Assessment of Water Quality in Alberta's Irrigation Districts

Second Edition

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November 2010

Citation
Little, J., Kalischuk, A., Gross, D., and Sheedy, C. 2010. Assessment of Water Quality in Alberta's Irrigation Districts, Second Edition. Alberta Agriculture and Rural Development, Alberta, Canada. 181 pp.

Revisions
The Second Edition includes revisions to the water quality index and arsenic values.

Published by
Irrigation and Farm Water Division
Alberta Agriculture and Rural Development
Lethbridge, Alberta, Canada

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Printed in Canada.

Copies of this report are available from:
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ACKNOWLEDGEMENTS

The authors acknowledge the contribution of expertise and advice from the following Alberta Agriculture and Rural Development (ARD) staff: Rod Bennett, Janna Casson, Jollin Charest, Sarah Depoe, Roger Hohm, Ross McKenzie, Barry Olson, Gerald Ontkean, Brent Paterson, Colleen Phelan, and Janelle Villeneuve. Technical support, including sample collection, quality analyses and control, and graphical support were provided by ARD staff including: Ki Au, Angela Chinn, Brian Coffey, Dana Coles, Alex Crook, Paul Graveland, Ward Henry, Mark Kadijk, Larry Kwasny, Gyan Mankee, Murray Peters, and Lawrence Schinkel. In addition, laboratory pesticide analytical support was provided by Paul Dawson, Dan Inaba, and Courtney Lamb, Agriculture and Agri-Food Canada. This project was made possible with funding support from the Canada Alberta Water Supply Expansion Program (CAWSEP) of Agriculture and Agri-Food Canada.

EXECUTIVE SUMMARY

Introduction

Alberta irrigates about 675 000 ha of land, which accounts for almost 70% of Canada's total irrigated land. About 520 000 ha of irrigated land is located within 13 irrigation districts of southern Alberta. Irrigated agriculture is an intensive and highly-valued industry, which accounts for a large portion of agricultural production in Alberta.

Water quality is intricately linked to agricultural production. Quality production is reliant upon clean source water. Water quality deterioration can occur in a number of ways, including land use impacts from agricultural, industrial, urban, and rural development.

Objectives

The objectives of this study were to:

i) assess the quality of source water used for irrigation from a food production perspective;
ii) assess changes in water quality as water travels through the irrigation infrastructure, from source water to return flow;
iii) determine if there are differences in water quality among the irrigation districts; and
iv) determine if there are differences in water quality between two types of conveyance systems.

Scope

This study examined about 80 sampling sites in Alberta's irrigation districts. Water was evaluated in 11 districts including the Mountain View (MVID), Aetna (AID), United (UID), Magrath (MID), Raymond (RID), Lethbridge Northern (LNID), Taber (TID), St. Mary River (SMRID), Bow River (BRID), Western (WID), and Eastern (EID) irrigation districts.

In addition, seven sites within the SMRID were sampled to determine differences in water quality between closed pipeline and open channel canals, and seasonal trends in water quality parameters.

Methods

Comprehensive Sampling of Irrigation Districts. Irrigation water was monitored at about 80 sites in 11 irrigation districts in 2006 and 2007. Sampling sites were chosen to capture water as it moved through the infrastructure of each irrigation district, from the source water to return flows. Sampling locations consisted of primary sites, where main source water enters the irrigation district; secondary sites, where canals branch off within the district for on-farm water supply; and return flow sites, where water exits the

irrigation district. Sites were grab sampled four times each year during the peak irrigation season (June to August).

Representative Sampling of the St. Mary River Irrigation District. The seven sites in the SMRID were grab sampled every two weeks from May to September in 2006 and 2007. A pipeline and open canal with the same source water were selected. The water traveled a maximum distance of about 5 km in the pipeline and 30 km in the canal.

Samples were analyzed for a suite of nutrient, metal, major ion, salinity, pesticide, and bacterial indicators.

Key Findings

1. **Water quality for irrigation in Alberta was generally good or excellent.**

   An Alberta irrigation water quality index was developed in order to summarize quality as assessed by irrigation guidelines. The index included metal, ion, salinity, pesticide, and bacterial indicators. Data were categorized as either 'excellent', 'good', 'fair', 'marginal', or 'poor' based on the scope, frequency, and magnitude of guideline exceedance.

   - Overall, water quality for irrigation was 'good' or 'excellent' for most of the source waters.
   - One secondary site in the WID and one return flow site in the EID were rated as 'marginal' for irrigation due to elevated concentrations of herbicides, bacteria and in the case of the WID, salinity.
   - Return flows generally had poorer quality than source waters.

   The WID scores were influenced by pesticides and salinity indicators. All samples that contained more than six pesticides were from the WID. Also, the highest total pesticide concentrations were observed in the WID. The relatively poorer water quality in the WID may be, in part, due to storm water runoff from the City of Calgary and the community of Chestermere. The lower scores observed in the EID returns were due to more frequent detections of dicamba, which has a very low irrigation guideline.

2. **Water quality guidelines for nutrients and metals were met the majority of the time.**

   Protection of Aquatic Life
   - The total phosphorus and total nitrogen guidelines for the protection of aquatic life were met in 78% and more than 93% of the samples, respectively.
   - The nitrite-nitrogen and ammonia-nitrogen guidelines for the protection of aquatic life were met more than 99% of the time.
   - The nitrate-nitrogen guideline for the protection of aquatic life was always met.

- Seven metals occasionally exceeded the protection of aquatic life guidelines. Compliance was 99% for iron, lead, manganese, and thallium; 98% for arsenic; 97% for zinc; and 87% for selenium.
- Aluminum concentrations met the protection of aquatic life guideline only 37% of the time.

Agricultural Uses

Irrigation

- Irrigation guidelines for boron, lithium, nickel, uranium, and vanadium were always met.
- Three metals occasionally exceeded irrigation guidelines. Compliance was 99% for iron, manganese, and aluminum.

Livestock

- The nitrate- plus nitrite-nitrogen guideline for livestock watering was always met.
- Two metals, aluminum and arsenic, complied to the livestock watering guidelines 99% of the time.

Other studies of irrigation water in Alberta had similar findings. Background concentrations from natural sources are likely the reason for the metal guideline violations.

3. **Pesticides were detected in most samples. Herbicide guidelines for irrigation were frequently exceeded, which may be of concern for some sensitive specialty crops.**

A number of the herbicides detected do not have guidelines. Further, guidelines for individual herbicides do not account for multiple pesticide compound detections in a sample.

- Of the 25 pesticides (17 herbicides, 8 insecticides) analyzed, nine herbicides were detected.
- Herbicides were detected in more than 90% of the samples.
- The most commonly detected herbicides were: 2,4-D (91%), dicamba (47%), and MCPA (38%).
- The 2,4-D guideline for the protection of aquatic life was met 99% of the time.
- Irrigation guidelines for dicamba and MCPA were frequently exceeded, with overall compliance of 54% for dicamba and 67% for MCPA.
- The MCPA, dicamba, triallate, bromoxynil and picloram guidelines for the protection of aquatic life or livestock watering were met in all samples.
- No Canadian guidelines exist for the agricultural herbicides clopyralid, dichlorprop, and mecoprop, which were detected in 12% or less of the samples.
- Forty percent of the samples contained more than two herbicides per sample. The maximum number of herbicides per sample was eight.

Herbicide irrigation guideline exceedances are common in Alberta's irrigation system. Generally, those herbicides with the greatest sales and environmental mobility are the compounds most commonly detected. No work has been to done to date to document potential impacts on crop production in Alberta.

4. **Source water quality varied among the districts for some parameters, even for districts within the same river basin.**

Some of the irrigation districts received water from the Oldman River Sub-basin (MVID, LID, AID, UID, MID, RID, LNID, SMRID, TID), while others received water from the Bow River Sub-basin (WID, BRID, EID). However, source water quality from districts within the same sub-basin was not consistent.

- The EID had significantly greater concentrations of nitrate-nitrogen in primary source waters compared to all other districts.
- The EID and AID had greater concentrations of some metals (aluminum, iron, lead - AID only, and vanadium) in primary source waters than all other districts.
- The WID source water quality appeared to be generally poorer than source waters of other districts due to greater numbers of pesticides detected as well as elevated nutrient concentrations and salinity.

The EID and AID metal concentrations were probably not a concern for crop production as they met irrigation guidelines the majority of the time. The metal concentrations may have be related to elevated total suspended solids concentrations.

Although high nutrient concentrations were not a concern for crop production, they may be of concern for efficient conveyance of water in irrigation canals as aquatic weed growth may be stimulated by dissolved nutrients in the water.

Water quality can be affected by a number of factors including flow velocity and volume in the canals, point and non-point source contributions from adjacent land use, and natural chemical or biological processes including mineral dissolution, denitrification, and assimilation in stream channels and reservoirs. Some of these factors may explain the differences in patterns among districts.

5. **Salinity and major ions were not a concern for most districts, with the exception of the BRID and WID.**

- Alkalinity, measured as $CaCO_3$, was greater in all irrigation districts than the recommended optimal alkalinity for greenhouse plants. However, impacts on field crop production were likely minimal.
- Irrigation guidelines for electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio (SAR), and chloride were met in more than

97% of the samples. The sulphate guideline for livestock water use was always met.

- All samples that exceeded guidelines for SAR or EC were from the BRID or WID, and included some source water.
- The BRID had significantly higher EC in source water than all the other districts. The BRID and WID had significantly higher SAR in their source waters than compared to all other districts.

It is unclear why increased salinity was observed in the BRID and WID, but not in the EID, which also has the Bow River as its source. Nonetheless, the levels of salinity and major ions were of minimal concern for successful crop production. However, monitoring should continue and future actions may be warranted to address these issues.

6. **Some degradation of water quality occurred as water flowed through the irrigation distribution system.**

- Five irrigation districts had significantly greater total phosphorus concentrations in return flows compared with source waters.
    - Increases in the LNID, RID, and UID were in dissolved and particulate fractions.
    - Increases in the SMRID and TID were in the particulate fraction.
- Six irrigation districts had significantly greater total nitrogen concentrations in return flows compared with primary source waters.
    - Increases in the LNID, MID, SMRID, TID, UID, and WID were in the organic form.
- Many districts had significantly higher salinity and major ion concentrations in return flows than those found in source waters.
    - For some variables, concentrations in secondary source sites were also higher than primary source sites.
- Pesticide detection frequencies were generally highest in the return flows, followed by the secondary and then primary source waters.
- Water quality parameters tended to peak at the beginning or near the end of the irrigation season when lower flows were common.

Water quality degradation occurs naturally as water travels downstream. However, water quality degradation may be augmented by land use activities and in particular, agricultural production. It has been well documented that as agricultural intensity increases, concentrations of nutrients and agricultural pesticides in agricultural streams tend to increase.

While the water quality received by the irrigation districts is critical for high quality crop production, it is also important to ensure that water returned to the aquatic environment and potential downstream users is of good quality. Measures to mitigate land use impacts on water quality should be undertaken where required.

7. **Pipelines generally had minimal effect on water quality, except for reducing bacterial indicators.**

    - While most water quality variables were not significantly different between the SMRID pipeline and earth canal, bacteria counts were significantly lower in the pipeline compared to the lower reaches of the earth canal.

Future Studies

Recommendations for future studies were provided at the end of this report and included suggestions for site selection, laboratory analyses, sampling regime, and data warehousing. It was suggested that an assessment of detailed linkages between land use in the irrigation districts and water quality would be beneficial.

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INTRODUCTION

Alberta has nearly 675 000 ha of irrigated land, the largest irrigated area in Canada. Most of this land (520 000 ha) is within 13 irrigation districts in the semi-arid southern region of the province. Irrigated agriculture is a highly-valued industry and an important part of the agricultural economy, with 16.2% of Alberta's agri-food gross domestic product produced on the 4.5% of agricultural land that is irrigated. Agriculture, and particularly irrigation, is also the single largest water user in the province, accounting for approximately 63% of water consumed in the province (AMEC 2007). While Alberta is relatively water-rich when compared to other areas of the world, water shortages are a reality that need to be addressed. The Saskatchewan River Basin has placed moratoriums on water licenses in its southern tributaries and the South Saskatchewan River Basin Water Management Review indicated that future limitations in water supply could impact current industries and constrain future growth.

In addition to concerns around supply, water quality continues to be an issue at the forefront of agricultural production and expansion. Recently, concerns around food safety related to the quality of irrigation source water have arisen in concert with increasing consumer pressure for "greener" agricultural production practices. Alberta has always had an important competitive advantage with the world's acceptance that the food produced in Alberta is considered safe and of good quality. However, there is a growing trend with consumers asking specifically how and where their food has been produced. Consumers want assurance from food processors, and the processors from producers, that their food is safe and that it has been produced in a manner that is sustainable for the environment.

Sustaining current agricultural production and agri-food processing is dependent on quality water supplies. Irrigation requires good quality water in order to prevent damage to sensitive crops from pesticides, salts, and trace metals. In the long term, low sodicity in irrigation waters is necessary to maintain soil structural stability.

Nutrients are a concern for irrigation conveyance systems and receiving water bodies. Excess nutrients, such as nitrogen and particularly phosphorus, can cause eutrophication of water bodies. The resulting excessive growth of aquatic macrophytes and algae can cause aesthetic issues for recreation and drinking water, difficulty in conveyance of water for irrigation or industrial purposes, and declines in oxygen concentrations that can result in fish kills and loss of biodiversity. In the United States, an estimated 80% of river kilometres are impaired by eutrophication, with agriculture indicated as the major contributor of non-point source pollution (U.S. EPA 1996). In addition, nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3) can be toxic to humans and other organisms. Nitrate from agricultural sources has been identified as a major threat to ground water supplies in the United States and Europe.

Pesticides are a concern from a human and an aquatic health perspective. Studies have found that a variety of human health problems including cancers (Alavanja et al. 2004), neurological disorders (Alavanja et al. 2004), reproductive problems (Clementi et al.

2008), and behaviour and developmental concerns (Colborn 2006) may arise from continued exposure to low doses of pesticides. Moreover, most pesticides have only had toxicological studies completed on a single active ingredient (Colborn 2006), but are commonly applied in mixtures, which may have synergistic effects. Low concentration mixtures of pesticides are commonly found in Alberta agricultural streams (Lorenz et al. 2008).

Pathogenic bacteria, such as verotoxigenic serotypes of *Escherichia coli* and *Enterococci*, can cause a wide array of human health problems and can also jeopardize the safety of water for irrigation, livestock watering, and recreation.

Studies in Alberta have found that concentrations of nutrients, bacteria, and pesticides in surface waters increase with greater agricultural intensity (CAESA 1998; Lorenz et al. 2008). Irrigated watersheds tend to have high agricultural intensity due to high rates of manure production, chemical expenditures, and fertilizer expenditures. Declining water quality in some agricultural streams has been attributed, in part, to contributions from irrigation return flows (Little et al. 2003; Depoe 2004). However, other studies have shown that irrigation return flows may have negligible or even beneficial effects on receiving stream water quality (Greenlee et al. 2000; Ontkean et al. 2005). The impact of return flow quality in the future may be minimized due to increasing irrigation efficiencies and reduced return flow volumes.

Water quality data from within Alberta's Irrigation Districts have occasionally been collected and described. The most comprehensive description was the Review of Irrigation District Water Quality (Madawaska Consulting 1997). This report compiled historical water quality data from 1977 to 1996 within six irrigation districts (Bow River, Eastern, Lethbridge Northern, St. Mary River, Taber, and Western irrigation districts). Source water quality of the irrigation districts usually met irrigation guidelines. In contrast, return flows more frequently exceeded irrigation guidelines, particularly for fecal coliform bacteria. Despite a large degree of variability, the data indicated that water quality is altered as it moves through the irrigation system, from source to return flows. Concentrations of salts, phosphorus, and pathogens generally increased, while nitrate and nitrite often decreased. Changes to water quality may be related to land use, topography, instream reservoirs, climate, or season. For example, herbicide detections seemed to be influenced by precipitation, with more detections and higher concentrations following rainfall. Also, water quality in the spring (April) tended to be worse than the remainder of the irrigation season.

Currently, Alberta Agriculture and Rural Development, Alberta Environment, and the irrigation districts collect water quality data within some of Alberta's irrigation districts. However, a shortfall of all the available water quality data is the inconsistency in data collection. Data are collected for multiple purposes, leading to a variety of sampling methods and frequencies, water quality variables, and laboratory analyses. As a result, data are not consistent or complete among the districts, and long-term trends of water quality changes in the districts cannot be discerned.

The objectives of this project were to monitor surface water quality throughout Alberta's irrigation districts in order:

i) To assess the quality of source water used for irrigation from a food production perspective;
ii) To assess changes in water quality as water travels through the irrigation infrastructure, from source water to return flow;
iii) To determine if there are differences in water quality among the irrigation districts; and
iv) To determine if there are differences in water quality among types of conveyance systems.

The first three objectives were assessed in the comprehensive study across all irrigation districts, while the fourth objective was assessed in a more detailed study within the St. Mary River Irrigation District.

METHODS

Sampling Sites

Irrigation water was monitored in 11 of the 13 irrigation districts of Alberta during the irrigation seasons (May to October) of 2006 and 2007. These districts included Mountain View (MVID), Aetna (AID), United (UID), Magrath (MID), Raymond (RID), Lethbridge Northern (LNID), Taber (TID), St. Mary River (SMRID), Bow River (BRID), Western (WID), and Eastern (EID) (Table 1). Specific sampling sites were not designated in the Leavitt (LID) and Ross Creek irrigation districts; however, source water quality upstream of the LID was captured.

Sampling sites were chosen to capture water as it moved through the infrastructure of each irrigation district, from the source water to return flows (Appendix 1). Sampling locations consisted of primary sites, where main source water enters the irrigation district; secondary sites, where canals branch off within the district for on-farm water supply; and return flow sites, where water exits the irrigation district. Samples were also taken at the outlets of major reservoirs prior to entrance into the districts. Most of the return flow sites had relatively large and continuous flows, and returned water to natural streams or rivers (Table 2).

Nomenclature of the sampling sites was as follows:

- First 1 to 3 letters in front of the dash: Designates the owner of the infrastructure where the site was sampled, which may be either the irrigation district (e.g., W is in the WID, and LN is in the LNID) or Alberta Environment (e.g., AEP = Alberta Environment Project). The SMRID was divided into three regions (SMW = SMRID west, SMC = SMRID central, SME = SMRID east).
- The letter after the dash: Designates the water as primary source water (P), secondary source water (S), or return flow (R).

- Number: Types of sites were sequentially numbered within each irrigation district (e.g., U-R2 is one of two return flow sites in the UID).

Comprehensive Study. The comprehensive study area initially included 80 sites throughout the 11 irrigation districts, but the W-R1 site was sampled in the wrong location and was removed from the dataset (Table 1, Fig. 1). One additional site was sampled at the request of the BRID in 2007 (BR-R6). The sites were grab sampled four times during the peak irrigation season (June to August) in 2006 and 2007. Sampling dates were selected to coincide with dry periods, when irrigation was occurring in the area. Sampling of the districts typically occurred within one week, and where possible, upstream districts were sampled prior to downstream districts (Appendix 2).

Representative Study. The representative study area included seven sites within the St. Mary River Irrigation District (Fig. 2). Two of the representative sites (SMC-S3 and SMC-R4) were also part of the Comprehensive Study. The pipeline and canal selected had the same source water (SMC-S3). Two pipeline and three canal sites were then chosen to examine water quality as it flowed through the conveyance structures. The distance between the two pipeline sites was about 5 km and the distance between the three canal sites was about 11 km. Site SMC-R4 served as a return flow site for the earth canal and was about 30 km from SMC-S3, which is the source water site. All seven representative sites were grab-sampled every two weeks during the irrigation season (June to October).

Sample Collection

Water samples were collected from the middle of the channel in triple-rinsed polyethylene bottles for nutrients, metals, and ions and in amber glass bottles for pesticide analysis. Water samples for metals were acidified to a pH < 2 with nitric acid, while the nutrients were acidified with sulphuric acid in the field. Bacteria samples were sub-sampled into small polyethylene bottles containing sodium thiosulphate. Water quality sampling QA/QC protocols were followed including duplicates, blanks, and spiked samples. Samples were kept on-ice in coolers for transport to the laboratory.

Water Quality Analysis

Samples were analyzed for a wide range of variables including nutrients, ions, physical variables, and bacteria (Table 3), metals (Table 4), and pesticides (Table 5). The original choice of parameters was determined in consultation with Alberta Environment, so that there was some congruence with Alberta Environment's long-term monitoring network. However, specific methods and variables were finalized based on the expertise of each of the laboratories used.

ALS labs provided analysis of nutrients, ions, and metals according to standard methods (APHA 1996). Due to laboratory equipment changes, detection limits for several metal analytes changed markedly (from 2 to 60 times) for Comprehensive Study sampling on August 27 and 28, 2007 (Table 4). Sampling occurred within AID, BRID, LNID, MID,

MVID, RID, and UID on these dates, and all affected metal variables were removed from the dataset as they were mostly non-detects that had undue influence on the dataset due to the inflated detection limit values. Except for pesticides, which do not occur naturally, variables that were below the limits of detection were replaced with half of the detection limit value for all sampling dates.

Bacteria were enumerated using the most probable number method (APHA 1996) by Maxxam Analytics, Calgary, Alberta in 2006 and 2007.

Agriculture and Agri-Food Canada, Lethbridge, Alberta completed the pesticide analysis, modifying the Lethbridge Research Centre method of Bruns et al. (1991) and Hill et al. (2002). Briefly, samples were filtered through glass wool, acidified to pH 2 with concentrated sulphuric acid and extracted by liquid-liquid partitioning with dichloromethane. Extracts were then dried with acidified Na_2SO_4, concentrated and methylated using diazomethane, transferred to hexane, and adjusted to a final volume of 10 mL. Esterified extracts (2 µL) were analyzed using a Hewlett Packard 6890 Series GC with a HP 5973 mass selective detector in selected ion monitoring mode.

Statistical Analysis

All data were log (x+1) transformed prior to analysis to minimize the impact of outliers on the statistical analysis. Data were analyzed using SAS version 9.1 (SAS Institute 1999-2008, Cary, NC) and XLStat 2009.4.27 (Addinsoft, 2005-2009).

Principal Components Analysis (PCA) was used to examine patterns within the data set. This method is especially useful for transforming data sets with a high degree of collinearity (or highly correlated variables) into a smaller number of unrelated variables or eigenvectors that explain the greatest amount of variation in the data set. Variables and/or sampling sites that are close to each other along the axes are more similar than those further away in the ordination space.

The Mixed procedure in SAS with the repeated measures and lsmeans options and the compound symmetry variance structure was used to compare differences in the fixed effects of site type within the individual irrigation districts and to compare each site type (primary, secondary and return flows) across the irrigation districts ($p<0.05$). Probabilities for multiple comparisons were adjusted using the Tukey-Kramer adjustment. Although the Mixed procedure is parametric, it is extremely robust to non-normal distributions. It differs from general linearized models or ANOVA in that errors can be estimated independently. Therefore, it is useful for examining data that may be serially or temporally correlated, such as data that are collected downstream or on a repeated basis, which may violate the assumption of independence of observations. Sites at the outlets of reservoirs and/or upstream of irrigation districts (prefix AEP) were not included in this analysis. Data were displayed as boxplots. Data within the shaded box represent the portion of the data between the 25^{th} and 75^{th} percentiles (ie. the middle half of the data), while the horizontal line in the box represents the median. The upper and

lower lines represent the 90th and 10th percentiles of the data, respectively, while the circles represent outliers above the 90th and below the 10th percentiles.

Alberta Irrigation Water Quality Indices

Two water quality indices were developed in order to summarize and visually display the data from all of the sites. An index is a tool for comparing data from within the same study, but there are numerous water quality indices that vary in the number of variables tested, sampling frequency, and objectives. Therefore, index results must be interpreted with caution and not compared among studies.

Although a draft of the Canadian Environmental Sustainability Indicators (CESI) irrigation water quality index was recently released (Guy et al. 2009), we chose to develop the Alberta Irrigation Water Quality Index and an Index for the Protection of Aquatic Life as opposed to using the CESI index for the following reasons:

i) Many of the parameters used in the CESI index are not relevant for Alberta water and soil conditions as they are of concern only for acidic soils or for micro-irrigation, which accounts for only a small fraction of irrigation in Alberta.
ii) In addition to the impact of irrigation on crop health, equipment, human health and soil structure, we also wanted to evaluate the potential impact of return flow streams on receiving water bodies, which is not evaluated in the CESI index.
iii) The division of the CESI index into four categories has the potential to overweight certain parameters, especially those with single indicators.

The variables and objectives used in the Alberta Irrigation Water Quality Index (AIWQI) and the Alberta Irrigation Protection of Aquatic Life index (AI-PALWQI) are listed in Table 6. Both indices use all applicable indicators with CCME guidelines for either irrigation, protection of aquatic life, or recreation that were monitored in the study. Indicators with CCME guidelines that only applied to acid soils were excluded from the index as soils in the irrigated areas of Alberta are typically alkaline. Guidelines for SAR used in the AIWQI were based on Buckland et al. (2002). Provincial PAL guidelines for TP and TN and recreation guidelines for bacteria (Alberta Environment 1999) were included in the PAL WQI. Where there was a range of guidelines due to the varying crop tolerances, the most sensitive value was used in the AIWQI so as to protect all crops. Ammonia guidelines were calculated based on temperature and pH, as it is more toxic at higher temperatures and lower pH values (CCME 1999). Copper and lead objectives were calculated based on hardness as they are more toxic in softer water.

RESULTS AND DISCUSSION

Principal Components Analysis

The first two axes of the principal components analysis (PCA) accounted for 39.4% of the variation among the sites (Fig. 3). The first axis ($\lambda = 0.236$) was composed of variables related to salinity, with total nutrients, bacteria, pesticides, and a few metals (Li,

Se, Sb, Hg, and Sn) also contributing. The second axis ($\lambda = 0.158$) was positively correlated with several metals (Al, Co, Fe, Ti, Pb, V, Zn, As), TSS, and the bacteriological variables and negatively correlated with Mo, pH, CO_3, and NH_3-N.

Generally, sites within the same irrigation districts had similar ordination scores. Sites from the BRID and WID had the highest axis 1 scores, indicating these sites had greater ionic, nutrient, and pesticide concentrations. In general, return flow sites also had greater axis 1 scores. Primary and secondary sites, as well as return flows from some of the irrigation districts in the southwestern region of the study area (MVID, UID, AID) had the lowest axis 1 scores, indicating lower ionic and nutrient concentrations.

The greatest axis 2 scores were observed in return flows from the LNID, RID and UID. These sites tended to have the greatest concentrations of metals, bacteria, and total suspended solids. Conversely, primary and secondary sites from the BRID, EID, MVID and SMRID and the SMC-R2 site had greater NH_3-N and pH values, but lower concentrations of bacteria, metals, and TSS.

Nutrients

Mean nutrient concentrations for each irrigation district and site type are presented in Table 7.

Total Phosphorus. The total phosphorus (TP) guideline for the protection of aquatic life (0.05 mg L^{-1}, Alberta Environment 1999) was exceeded in 22.1% (140/634) of the comprehensive study samples. Overall compliance was greatest in the AID (100%) and least in the RID (50.0%) and WID (68.8%) irrigation districts. In general, return flows had lower levels of compliance in comparison to primary and secondary sites, except for in the AID and EID, which had similar compliance levels among site types (Fig. 4). Six districts had 100% compliance in primary sites (AID, LNID, MVID, RID, TID, and UID) compared to three districts with 100% compliance in secondary sites (LNID, MID, and UID) and one in return flow sites (AID). The minimum compliance levels were found in the WID for primary (79.2%) and return flows (12.5%), while the TID and WID had the lowest compliance (75.0%) in the secondary sites (Fig. 4).

Total phosphorus concentrations ranged from below the detection limit to a maximum of 0.54 mg L^{-1} at the SMC-R2 site. Median TP concentrations were below the detection limit at 33 sites while the greatest median TP value was observed at the SMC-R2 site. Six sites always had TP concentrations below detection limits (AEP-S1, AEP-S2, E-S2, LN-P1, T-P1, W-P1).

Significant increases in TP concentrations were observed among primary, secondary, and return flow sites in the LNID, RID, SMRID, TID, and UID (Fig. 5, Table 7, Table 8), indicating a degradation in water quality as water flowed through these districts. In the remaining six districts, there were no significant differences in TP among site types.

There were no significant differences in TP concentrations among primary sites in the different irrigation districts; however, differences may have been masked by the high detection limits used (0.02 mg L^{-1}). Among secondary sites, TP concentrations were significantly greater in the WID compared to the EID, LNID, and UID. There were also significant differences in return flow sites, with significantly greater TP concentrations in the WID compared to most other sites except the RID and LNID. The RID return flow sites also had significantly greater TP concentrations compared to return flows in the BRID, TID, MVID, EID, and AID (Fig. 5). The LNID return flows had significantly greater TP concentrations than the EID return flow sites.

For the representative study, median concentrations were all below the detection limit, with mean values ranging from 0.013 to 0.020 mg L^{-1}. Only four of the 146 samples (2.7%) exceeded the 0.05 mg L^{-1} guideline and these observations occurred at four different sites. When higher concentrations occurred, they often were observed in May, but monthly differences were minimal (Fig. 6). As such, there were no differences among sites.

A 1997 review of 44 sites in six irrigation districts reported a greater number of TP outliers in WID source water sites (Madawaska Consulting 1997). In addition, the EID and LNID tended to have higher TP concentrations in source waters. However, no statistical analysis of the data was completed. The same study reported greater TP concentrations in LNID return flows and lower TP concentrations in EID return flows. Maximum concentrations from the reviewed return flow data were greater than those found in our study, ranging from 0.720 mg L^{-1} in the EID to 3.10 mg L^{-1} in the LNID. These differences are likely due to the timing of sampling, which differed between the studies.

In a long-term study of agricultural streams, Lorenz et al. (2008) reported annual flow-weighted median TP concentrations in irrigation return flow streams ranging from 0.060 to 0.742 mg L^{-1}. Although our sites only encompassed summer months and were not flow-weighted, there was no seasonality detected in the March to October samples in the Lorenz et al. (2008) study. Twenty-two of the 32 return flow sites in the current study had median concentrations below 0.060 mg L^{-1}. However, the greatest median concentrations at the SMC-R2 site was greater than the average median concentrations at the Battersea Drain site of the LNID (0.078 mg L^{-1}) and the New West Coulee site of the BRID (0.098 mg L^{-1}).

Dissolved Reactive Phosphorus. Dissolved reactive phosphorus (DRP) concentrations ranged from below the detection limit to 0.31 mg L^{-1} at the W-S4 site. Twenty-six sites had no detections of DRP. Median DRP concentrations were greatest at the return flow site R-R1 (0.08 mg L^{-1}) and were below detection at 63 sites.

Three irrigation districts had significantly greater concentrations of DRP in return flows compared with primary sites and secondary sites (where applicable), including the LNID, RID and UID (Fig. 7, Table 7, Table 9). The remaining eight districts had similar DRP concentrations among site types. Greenlee et al. (2000) noted increases in DRP between

block inflows and outflows in two LNID locations, but not in other LNID or BRID locations.

Only return flow sites showed significant differences among the irrigation districts (Fig. 7). The RID and WID return flows had significantly greater DRP concentrations than return flows in the other irrigation districts.

For the seven representative sites, there was a narrow range of DRP observed, from below detection to 0.04 mg L^{-1} at the SMC-S3 site. Median values were all below detection, while mean values had a narrow range from 0.005 mg L^{-1} at SMC-R4 to 0.009 mg L^{-1} observed at the block inflow SMC-S3. Where higher concentrations were observed, they occurred towards the beginning of the irrigation season (Fig. 8). Maximum concentrations were observed in 2006. No significant differences were observed among the representative sites.

Ammonia-N. Ammonia-N (NH_3-N) guidelines for the protection of aquatic life were exceeded in five of the 634 samples (0.8%), including two samples from EID secondary sites, one from an EID primary site, one BRID return flow, and one SMRID return flow. Guidelines were never exceeded in the remaining districts; however, there were 19 samples taken in 2006 and seven samples in 2007 that could not be assessed for possible guideline exceedance. Ammonia-N guidelines are temperature and pH dependent as aquatic toxicity is greater at greater pH values and higher temperatures. In cases of very high pH (>9.2), the guidelines for NH_3-N were below the detection limit used in the study, and therefore, the exceedance rate could be greater than reported here. Four irrigation districts in 2006 (BRID, TID, SMRID, and UID) and two irrigation districts in 2007 (BRID and SMRID) had sites with pH >9.2. Maximum pH values were 9.9 in 2006 and 9.6 in 2007.

Ammonia-N concentrations ranged from below the detection limit to 0.31 mg L^{-1} at the E-S6 site. Median values were below the detection limit at all sites.

Within nearly all individual irrigation districts, there were no differences among primary, secondary, and return flow sites, except for the LNID where there were significantly greater concentrations of NH_3-N in primary sites compared with secondary and return flow sites (Fig. 9, Table 7, Table 10). The LNID contains a high density of confined feeding operations (CFOs), and Hao et al. (2005) reported that atmospheric NH_3 contributed between 4 and 122 kg NH_3 per hectare per year to surface waters in the region. However, there were no significant differences in NH_3-N concentrations among the irrigation districts for the different site types.

For the representative samples, concentrations ranged from below detection to 0.18 mg L^{-1} at the SMC-PL2, with NH_3-N detections occurring at only three of the seven sites (SMC-S3, SMC-E2, SMC-PL2). No ammonia guidelines were exceeded. Detections only occurred in May or October (Fig. 10), when flows were reduced. There were no significant differences among the representative sites.

Nitrate- and Nitrite-N. Nitrate-N (NO_3-N) concentrations in the comprehensive sites always met Canadian Council of Ministers of the Environment (CCME) guidelines for the protection of aquatic life (CCME 1999), and NO_3+NO_2-N always complied with the guidelines for livestock watering (CCREM 1987). However, NO_2-N guidelines (CCREM 1987) were exceeded in six of the 634 samples (0.95%). Nitrite-N guidelines were exceeded in five different irrigation districts, including return flows in the AID, MVID, and UID, a secondary site in the BRID, and a primary site in the RID (Fig. 11).

Maximum NO_3-N concentrations ranged from below detection to 2.78 mg L^{-1} at the W-S1 site. More than half of the sites (46) were always below detection limits. Median NO_3-N concentrations were below detection limits at 70 of the 80 sites, while the greatest median concentrations were observed at two primary sites (0.585 mg L^{-1} at AEP-P3 and 0.365 mg L^{-1} at E-P1).

Nitrate-N concentrations were significantly greater at primary sites compared to secondary sites (where present) and return flow sites in the LNID, EID, RID, and UID (Fig. 12, Table 7, Table 11). In the EID, secondary sites also had significantly greater concentrations of NO_3-N than return flow sites. These findings were similar to those reported by Madawaska Consulting (1997), showing decreases in NO_3-N moving through the irrigation system, likely due to dentrification.

Compared to primary sites in other irrigation districts, the EID had significantly greater concentrations of NO_3-N (Fig. 12, Table 11). Previous studies have also reported elevated NO_3-N concentrations in EID source waters (Madawaska Consulting 1997). It should be noted that only one site was considered as primary in EID. Primary sites in the RID also had significantly greater NO_3-N concentrations than primary sites in the SMRID, WID, AID, BRID, MVID, and TID, with the latter four districts having no detections of NO_3-N at the primary sites. There were also significant differences in NO_3-N concentrations among secondary sites, with WID secondary sites having greater NO_3-N concentrations than BRID secondary sites. A different pattern emerged among return flow sites as the MID and WID sites had significantly greater NO_3-N concentrations than the other return flow sites.

For the representative study, NO_3-N ranged from below detection to 0.65 mg L^{-1} at the SMC-S3 site. Maximum concentrations were observed in July 2006 for the three sites where NO_3-N was detected (Fig. 13).

The maximum NO_2-N concentration 0.1 mg L^{-1} was observed at R-P1, while two other sites had values of 0.09 mg L^{-1} (MV-R1, A-R1). Sixty-nine of the 82 sites had maximum NO_2-N concentrations below detection limits, while all sites had median NO_2-N values below detection limits.

Significant differences in NO_2-N concentrations were only observed in two districts (Table 12). In the LNID, greater concentrations were found in primary sites compared with secondary and return flow sites, while in the WID, greater NO_2-N concentrations were found in return flow sites compared to secondary and primary source sites (Fig. 14).

Nitrite-N concentrations were similar for primary and secondary sites among the districts; however, minor differences were observed in the return flow sites, where NO_2-N concentrations were significantly greater in UID return flow sites compared with BRID return flow sites. Madawaska Consulting (1997) also reported decreases in NO_2-N moving through the irrigation system in a review of six irrigation districts.

Nitrite-N was not detected in any of the representative samples.

Total Kjeldahl Nitrogen and Total Nitrogen. Total Kjeldahl nitrogen (TKN) concentrations ranged from below detection to 5.3 mg L^{-1} at BR-S5. Total Kjeldahl nitrogen was not detected at four sites (AEP-S2, LN-P1, AEP-S1, and U-P1), while a total of eight sites had median TKN values below detection limits. The greatest median concentration was found at the SMC-R2 site, with a concentration of 2.1 mg L^{-1}.

There were significant differences in TKN concentrations among site types in five irrigation districts (Fig. 15). In the LNID, SMRID, and UID, concentrations were significantly higher at return flow sites compared with both primary and secondary sites, while significant differences were observed between return flow and primary sites in the TID and in the RID, which had no secondary sites.

There were also significant differences in TKN concentrations among the irrigation districts for the individual site types (Table 13). Primary sites in the MVID and WID had significantly greater concentrations than primary sites in the RID, LNID, and UID (Fig. 15, Table 7). Secondary sites in the BRID had significantly greater TKN concentrations compared with most other secondary sites, except for the TID. Concentrations of TKN were also significantly greater in TID secondary sites compared to UID secondary sites. In the return flow sites, the SMRID and WID had significantly greater TKN concentrations than in the AID, EID, MID, RID, and UID. The BRID return flow sites also had significantly greater TKN concentrations than in the AID, EID, MID, and UID.

For the seven representative sites, TKN ranged from below detection to 0.8 mg L^{-1}, with the greatest mean concentration at the SMC-PL2 site (0.28 mg L^{-1}) and the greatest median concentrations (0.30 mg L^{-1}) at the SMC-S3 and SMC-E1 sites. Concentrations of TKN tended to be greater at the beginning of the irrigation season, but not all sites followed this pattern (Fig. 16).

The total nitrogen (TN) guideline (1.0 mg L^{-1}, Alberta Environment 1999) was exceeded in 47 of the 634 samples (7.4%). Total nitrogen concentrations never exceeded guidelines in five irrigation districts. In the remaining six districts, compliance was 81.4% in the SMRID, 87.5% in the WID and 90% or greater in the BRID, EID, TID, and MID (Fig. 17). Among primary sites, the EID and BRID had the lowest compliance (87.5%). Among secondary sites, compliance was lowest in the BRID (81.2%), mostly due to the BR-S2 site, which receives natural runoff and irrigation spill water. Among return flow sites, the SMRID had the lowest compliance (72.7%).

For the comparison between site types, similar patterns were observed for TN and TKN; however, significant differences were also observed in the EID, where primary sites had significantly greater TN concentrations than either secondary or return flow sites (Fig. 18). Concentrations of TN were greater in the return flow sites than source water sites for MID, UID, and WID. In LNID, TN was significantly greater in the return sites than the secondary source sites and significantly greater in the secondary than the primary source sites. The TID had significantly greater TN concentrations in the secondary and return sites than the primary sites.

Total nitrogen concentrations at the primary sites in the EID had significantly greater concentrations than most other districts except for the MVID (Fig. 18, Table 7, Table 14). The MVID primary sites had significantly greater concentrations of TN than the primary sites in the TID, LNID, and UID, while the WID primary sites significantly differed from those in the UID. Total nitrogen concentrations at the secondary sites were significantly greater at BRID sites compared to most of the other districts. Among return flow sites, concentrations of TN were significantly greater in the WID than most of the districts except BRID, SMRID, and TID. The SMRID and BRID TN concentrations were significantly greater than those in the AID, EID, and UID return flow sites.

For the representative sites in the SMRID, TN concentrations ranged from below detection to 1.15 mg L^{-1} at the SMC-S3 site. Two of the 146 samples (1.37%) exceeded the TN guideline. Where greater concentrations were observed, they tended to occur at the beginning of the season; however, there were no significant differences among sites (Fig. 19).

Salinity and Major Ions

Since there was a high degree of collinearity (Fig. 3) observed among the salinity variables, not all variables will be examined in detail. Means by irrigation district and site type are presented in Table 15.

Electrical Conductivity. Electrical conductivity measures the ability of a solution to conduct an electrical current, which is directly related to the concentration of dissolved salts in solution. Excess salts in the plant root zone can cause moisture stress as salts increase the amount of energy plants must expend in order to take up water. In addition, individual ions can have deleterious effects. For example, sodium from sprinkler irrigation can be directly toxic and cause defoliation of sensitive plants.

Electrical conductivity (EC) ranged from 172 µS cm^{-1} at the AEP-P1 site to a maximum of 1480 µS cm^{-1} at the W-S3 site. The lowest mean and median values were observed at the Belly River Diversion sites (AEP-P1, AEP-S1, AEP-S2) and the U-S1 site, all of which had mean and median EC values less than 200 µS cm^{-1}. Sites BR-R3, BR-S2, and W-R2 had mean and median EC values greater than 700 µS cm^{-1}. Irrigation waters with EC less than 1000 µS cm^{-1} are considered safe for irrigation as long as SAR values are also below 5.0 (Buckland et al. 2002). There were five samples (one primary, two

secondary, and two return flow) from the WID that were above the 1000 µS cm^{-1} guideline.

There were significant differences in EC within five of the irrigation districts (LNID, MID, RID, SMRID, UID) (Table 16), with significantly greater concentrations in the return flow samples compared to primary sites and most secondary sites (Fig. 20). The greatest increases were observed in the MID. Electrical conductivity remained elevated throughout the irrigation network in the BRID and remained low throughout the AID and MVID.

Among primary sites, the BRID had significantly greater EC than all other irrigation districts, followed by the WID, which also had significantly greater EC than the remaining nine irrigation districts (Fig. 20). Electrical conductivity was also significantly lower at the AID, UID, and MVID primary sites compared to the EID, SMRID, and TID primary sites. Similar patterns were observed among the secondary sites with BRID secondary sites having the greatest EC, followed by significantly lower EC in the WID. Similar EC values were found in the EID, LNID, SMRID, and TID, which were greater than those observed in UID secondary sites. Among return flow sites, EC in the BRID was significantly greater than most other districts, except for WID return flows. In turn, the WID return flow sites were significantly greater than all of the remaining sites, with the exception of the MID sites. The MID return flows had significantly greater EC concentrations than six of the sites, while the TID, SMRID, EID, and RID had significantly greater EC concentrations in their return flows compared to those in the MVID, UID, and AID.

For the representative sites, EC ranged from 190 to 619 µS cm^{-1}, with greater values observed at the beginning of the irrigation season (Fig. 21). Values of EC tracked each other closely among sites; and therefore, there was only a narrow range of mean (291 to 315 µS cm^{-1}) and median (291 to 298 µS cm^{-1}) values and no differences in EC among sites.

As in our study, Madawaska Consulting (1997) reported that the source water in the BRID had the poorest water quality with respect to salinity of the six irrigation districts examined, while the WID source water had numerous salinity outliers. In contrast with our study, the BRID showed significant increases in EC in one block inflow and outflow (Greenlee et al. 2000), whereas in our study, EC remained elevated throughout the irrigation network. Also, in our study, there were significant increases in EC moving through the LNID network; however, there were no EC differences reported in a single inflow and outflow from the LNID (Greenlee et al. 2000).

Total Dissolved Solids. Total dissolved solids (TDS) are related to EC and therefore, have very similar patterns. Total dissolved solids ranged from 89 mg L^{-1} at the AEP-P1, AEP-S1, and MV-P1 sites to 977 mg L^{-1} at the W-S3 site. The highest mean concentrations were observed at the BR-R3 site (507 mg L^{-1}) (median = 506.5), while the lowest mean TDS concentrations were observed at the Belly River Diversion sites (< 116 mg L^{-1}). The CCME irrigation guidelines (CCREM 1987) for TDS have a wide range and

are as low as 500 mg L^{-1} for some fruit and vegetable crops and as high as 3500 mg L^{-1} for most cereals and sugar beets. Only 2.5 % (16/631) of samples exceeded the lower threshold, with the most exceedances in the BRID and WID. Primary sites exceeded the threshold in the WID, while secondary sites in the BRID and WID also exceeded this value (Fig. 22). Return flow samples in the BRID, MID, and WID also exceeded this TDS value (Fig. 22).

Within the individual irrigation districts, patterns were the same as observed for EC, except that there were significant differences in TDS within the TID and WID and no significant differences in TDS within the UID (Fig. 23, Table 17).

Similar patterns to EC were also observed among the various site types. Among the primary sites, TDS was significantly greater at the BRID than at all other sites, followed by the WID, which was also significantly different from the remaining sites. There were also similar patterns among the secondary sites with BRID having the greatest and the WID having the second greatest TDS concentrations, and the UID having the lowest TDS concentration. In the return flows, the greatest TDS concentrations were measured in the BRID and WID, which were significantly greater than all other districts. These districts were followed by the MID, which had significantly greater TDS concentrations than most other sites, except for the TID and EID return flow sites. The lowest TDS concentrations were found in the MVID, UID, and AID.

Total dissolved solids in the seven representative sites ranged from 141 to 257 mg L^{-1}, with the greatest values observed in the May samples. There were no differences among the sites as TDS values followed very similar patterns (Fig. 24).

Greenlee et al. (2000) reported differences in TDS concentrations between a block inflow and outflow in the BRID, but no changes in TDS concentration were observed in a similar evaluation in the LNID. The differences in the observed patterns were attributed to evaporation losses that concentrate salts and the influence of soil salinity.

Sodium Adsorption Ratio. The sodium adsorption ratio (SAR) is a measure of the potential sodium hazard for crops and soil. When sodium (Na^{+}) occupies cation-exchange sites at the expense of more stabilizing ions (Ca^{2+}, Mg^{2+}, CO_3^{-2}, and HCO_3^{-}), soil stability can be compromised resulting in dispersion of clay and breakdown of aggregates. These processes can result in soil expansion and surface crusting, which reduce infiltration and therefore, can reduce crop growth due to moisture stress.

Sodium adsorption ratios ranged from 0.045 at the AEP-S1 and U-P1 sites to 5.2 at the W-S3 site. The highest mean and median SAR values were observed at the BR-S2 site (2.69), while the lowest mean and median values were observed at the Belly River Diversion sites and the U-P1 and U-S1 sites, all with mean and median SAR values less than 0.12. Irrigation water with SAR values less than 4 and EC less than 1000 µS cm^{-1} is considered safe for irrigation in all conditions (Graveland 1983), while more recent studies have suggested that SAR values of up to 5 and EC less than 1000 µS cm^{-1} are safe for supplemental irrigation (Buckland et al. 2002). The majority of sites were below

these thresholds, with four samples from the WID having SAR values greater than 4 and one having an SAR greater than 5. Most of these samples also had EC values in excess of 1000 $\mu S\ cm^{-1}$. However, only one of the values was observed in a secondary supply canal.

There were significant differences in SAR among site types in seven of the 11 irrigation districts (Table 18). Return flows had significantly greater SAR values than primary sites in the EID, LNID, MID, RID, SMRID, TID, and UID (Fig. 25). Return flows were also significantly different than secondary sites in the LNID, TID and UID, while secondary sites had significantly greater SAR than primary sites in the EID and LNID. The greatest changes were observed in the MID.

Among the primary sites, the BRID and WID had significantly greater SAR, than the other districts (Fig. 25). The UID had significantly lower SAR than the BRID, SMRID, TID, EID, and WID. There were similar patterns among the secondary sites, except differences in SAR between the BRID and WID were significant, with BRID having greater SAR values than WID. Among return flow sites, the SAR at the BRID and WID sites was significantly greater than most other districts, except for the MID. Similar SAR values were found in the MID and TID, which were greater than most (TID) or all (MID) of the remaining sites. The AID, MVID, and UID had the lowest SAR values of the return flow sites.

Previous studies have also reported elevated salinity concentrations in the BRID as well as increased numbers of outliers in the WID source waters (Madawaska Consulting 1997). Greater SAR concentrations were also reported in WID return flows, while lower SAR values were observed in the TID (Madawaska Consulting 1997). Greenlee et al. (2000) reported increases in SAR in a block inflow and outflow in the LNID in one year, but no changes in the other year or at the BRID block inflow and outflow sites.

For the representative sites, SAR ranged from 0.21 to 1.25, with peak values early in the season, followed by a steady decline until SAR leveled out or increased slightly in October (Fig. 26). There were no differences among sites.

Alkalinity. Alkalinity is a measure of the buffering capacity of a solution and is a sum of the concentrations of carbonates, bicarbonates, and hydroxides. Although there are no guidelines for alkalinity in Canada, Cox (1995) reported that the water with alkalinity between 30 and 60 mg L^{-1} was optimal and ranges from 0 to 100 mg L^{-1} acceptable for greenhouse irrigation. A combination of high pH and high alkalinity may cause changes in the pH of the growing medium and some trace element deficiencies, especially for plants in small containers with low volumes of substrate. High levels of carbonates and bicarbonates can also cause blockages in irrigation equipment or precipitation of calcium and magnesium ions, thereby increasing SAR.

Alkalinity (as $CaCO_3$) ranged from 67 mg L^{-1} at the W-S2 site to 352 mg L^{-1} at the W-P1 site. The greatest mean concentrations were observed at the BR-R2 site (170 mg L^{-1}) and the greatest median concentrations were observed at the BR-P1 site (166 mg L^{-1}), while

the lowest median alkalinity values were observed at the AEP-P1 and T-S3 sites (100 mg L^{-1}). Optimal alkalinity concentrations are between 30 and 60 for most greenhouse plant species (Cox 1995); however, surface waters in Alberta tend to be well above this threshold naturally. The impact of this on crop health is likely negligible for field crops. Further, as discussed previously, most SAR values were in the safe irrigation range.

Significant differences in alkalinity between site types within irrigation districts were found in the BRID, MID, RID, and WID (Table 19, Fig. 27). In most cases, return flows had significantly greater alkalinity than the primary and secondary sites, except for in the WID, where return flows and primary sites had similar alkalinity concentrations. Differences in the MID, RID, and WID sites were mostly due to significant differences in bicarbonate, while carbonate and bicarbonate contributed to the differences in the BRID sites (data not shown).

There were also significant differences in alkalinity among site types of the various irrigation districts (Table 19). Among primary sites, the greatest alkalinity was found in the BRID, which was significantly greater than all other districts except for the EID (Fig. 27). The differences were likely due to the significant differences in bicarbonate as differences in carbonate among primary sites were not significant (data not shown). Among secondary sites, the BRID once again had significantly greater alkalinity than all other irrigation districts. The SMRID and EID secondary sites also had significantly greater alkalinity than the UID secondary sites. However, in the return flow sites, the WID, BRID, MID, and MVID all had similar alkalinity concentrations, with the WID and BRID having significantly greater alkalinity than the other seven irrigation districts. The MID return flows also had significantly greater alkalinity levels than those of the TID and UID. Bicarbonate and carbonate contributed to the differences in alkalinity in the secondary and return flow sites.

Alkalinity in the representative sites ranged from 86 to 150 mg L^{-1}, with a very narrow range of median values, ranging from 124 to 128 mg L^{-1}. There was greater seasonal variation in alkalinity, particularly in 2007; however, values among sites tracked each other quite closely and were not significantly different from each other (Fig. 28).

Chloride. Chloride (Cl^-) toxicity is the most common kind of specific ion toxicity for irrigation because Cl^- moves readily in the solution and can accumulate in plant leaves. In addition to accumulation by transpiration, Cl^- can be directly absorbed by leaves, which can be an issue for sprinkler irrigation (Ayers and Westcot 1994). Therefore, recommended guidelines are lower for sprinkler irrigation than surface irrigation.

Chloride concentrations ranged from 0.1 mg L^{-1} at four sites (AEP-S1, U-S1, U-P1, U-R2) to 65 mg L^{-1} at W-P2. Mean concentrations were highest at the W-R1 site (38 mg L^{-1}) and lowest at the U-P1 and U-S1 sites (less than 0.24 mg L^{-1}). All of the samples were below the CCME irrigation guideline of 100 mg L^{-1} (CCREM 1987), the level at which the most sensitive crops may be negatively affected by sprinkler irrigation.

There were significant differences in Cl^- concentrations among site types within five irrigation districts (Table 20, Fig. 29). Return flow concentrations were significantly greater than primary sites in the LNID, MID, RID, SMRID, and TID. Secondary sites also had significantly greater Cl^- concentrations than primary sites in the LNID and TID.

Among primary sites, the WID and BRID had the greatest Cl^- concentrations, which were significantly greater than all other districts (Fig. 29). Chloride concentrations in the EID primary sites were also significantly greater than the remaining eight districts, while the MVID and UID had the lowest Cl^- concentrations. There were also significant differences in Cl^- concentrations among secondary sites, with the WID and BRID again having significantly greater Cl^- concentrations than all other districts and the EID having greater Cl^- concentrations than the remaining districts. The TID and SMRID secondary sites had similar Cl^- concentrations that were significantly greater than those of LNID and UID secondary sites. The BRID and WID return flow sites had significantly greater concentrations of Cl^- than all other return flow sites, followed by the EID and TID, which were significantly different from each other and most of the remaining sites. The AID, MVID, and UID had the lowest Cl^- return flow concentrations.

For the seven representative sites, Cl^- concentrations ranged from 0.5 to 2.7 mg L^{-1}, with all sites having median values of 1 mg L^{-1}. Peak values were observed in May or June of 2006 and then decreased throughout the irrigation season (Fig. 30). Concentrations were greater in 2006 than in 2007.

Sulphate. Sulphate can contribute to salinity problems, but also can benefit crops by increasing fertility (Bauder et al. 2007).

Sulphate concentrations (expressed as SO_4^{-2}) ranged from 3.4 mg L^{-1} at the MV-R1 site to 467 mg L^{-1} at the W-S3. Mean concentrations were greatest at the BR-S2 (249 mg L^{-1}), while mean concentrations were below 5 mg L^{-1} at three sites (MV-P1, MV-R1, A-P1). None of the samples exceeded the CCME guideline for livestock watering (1000 mg L^{-1}, CCREM 1987).

There were significant differences in SO_4^{-2} concentrations within seven of the irrigation districts (Table 21). Return flow SO_4^{-2} concentrations were significantly greater than primary sites in the EID, LNID, MID, RID, SMRID, TID, and UID (Fig. 31). Unlike many other variables, there were elevated concentrations in many secondary sites compared to primary sites (EID, LNID, TID, UID) as well as differences between return flow sites and secondary sites in the same four districts (Fig. 31).

Among primary sites, the BRID had significantly greater SO_4^{-2} concentrations than any other district, followed by the WID, which had significantly greater SO_4^{-2} concentrations than the remaining nine districts (Fig. 31). The EID, TID, and SMRID had similar concentrations that were significantly greater than the RID, LNID, and MID. The UID, AID, and MVID had significantly lower SO_4^{-2} concentrations than the other districts. Among secondary sites, SO_4^{-2} concentrations were again significantly greater in the BRID than all other irrigation districts, followed by the WID. Conversely, secondary

sites in the LNID and UID were significantly lower than all other sites (Fig. 31). For the return flow sites, the BRID and WID had similar SO_4^{-2} concentrations, with the BRID concentrations being significantly greater than all remaining sites. Concentrations were similar between the WID and MID return flow sites, with the MID return flows having similar concentrations to those of the EID and TID return flows. Return flow SO_4^{2-} concentrations were similar among the EID, SMRID, RID, and LNID, which were significantly greater than the UID, which in turn, had significantly greater concentrations than the AID and MVID return flow sites.

Sulphate concentrations ranged from 18.4 mg L^{-1} to 98.0 mg L^{-1} in the representative sites. There were no significant differences among the sites. Most sites showed peak concentrations in June and then declined during the rest of the irrigation season (Fig. 32).

Metals

Silver (Ag), molybdenum (Mo), and tin (Sn) were not detected in any samples, while beryllium (Be), cadmium (Cd), and cobalt (Co) were only detected in single samples from the LNID. Chromium (Cr) and mercury (Hg) detections were also rare, occurring in only 5 and 14 samples, respectively. These rarely detected metals will not be discussed further.

The most commonly detected metals were barium (Ba), iron (Fe), and uranium (U), which were detected in 100% of the samples. Aluminum, arsenic, and manganese (Al, As, and Mn, respectively) were detected in more than 90% of the samples. Means for metal variables for each irrigation district and site type are presented in Tables 22 and 23.

Aluminum. Aluminum in irrigation water is primarily a concern for irrigation on acidic soils, as acid soils increase its availability for biological uptake and transport. The CCME irrigation limit of 5 mg L^{-1} is designed for continuous application on acidic soils, but is much higher (20 mg L^{-1} for up to 20 years) for neutral, alkaline fine-textured soils (CCREM 1987). Excess Al can affect root growth and interfere with plant nutrition (WHO 1997). In aquatic environments, Al can be acutely toxic or bioaccumulate in organisms, especially impacting the gills of fish.

Aluminum was detected in 96.5% of samples. The maximum concentration was 7.42 mg L^{-1} at the LN-R1 site, while the greatest mean concentration was observed at the same site (3.74 mg L^{-1}). Nearly 63% (380/607) of the samples did not comply with the guideline for the protection of aquatic life or the aesthetic objective for drinking water, while three of the 607 samples (0.49%), two in the LNID return flows, and one in a UID return flow, did not meet the guideline for livestock watering and irrigation. Compliance with the PAL guideline ranged from 0% of samples in the AID and RID to just below 90% in the MVID primary site (Fig. 33). Compliance rates tended to be greater in the primary and secondary sites.

There were significant differences in Al concentrations within nine of the irrigation districts (Table 24). Return flows had significantly greater concentrations than primary

and secondary sites in the BRID, LNID, MID, MVID, RID, UID, and WID (Fig. 34). Secondary sites also had significantly greater Al concentrations than primary sites in the WID. In contrast, the AID and EID had significantly greater Al concentrations in primary sites, compared with secondary and return flow sites.

Among the irrigation districts, primary sites in the AID and EID had significantly greater concentrations than most other districts. The secondary sites in the WID, LNID, and SMRID had significantly greater Al concentrations than the remaining secondary sites (Fig. 34). Return flow sites in the UID, LNID, and RID had significantly greater concentrations than in the MVID, AID, SMRID, BRID, TID, and EID (Fig. 34).

Aluminum concentrations in the representative sites ranged from 0.02 to 1.84 mg L^{-1}, with 80.3% (106/132) of samples exceeding the guideline for the protection of aquatic life. Aluminum concentrations were significantly greater in the SMC-S3 site compared to the SMC-PL2 and SMC-E2 sites, while the SMC-E1 site was significantly greater than the SMC-PL2 site ($F = 3.42$, $p=0.0037$, $df = 6,125$) (Fig. 35).

Overall, the Al concentrations in the irrigation waters were greater than expected and a concern for livestock watering and the protection of aquatic life.

Antimony. Antimony (Sb) is found naturally and is used as a flame retardant and in batteries, pigments, ceramics, and glass. It is toxic to humans and aquatic organisms.

Antimony was detected in 350 of the 607 samples (57.7%). Detection frequencies were similar among most irrigation districts and ranged from 50 to 69% (Fig. 36). Concentrations ranged from below detection to 0.0074 mg L^{-1} at the BR-R3 site. The BR-R3 site also had the greatest mean concentration observed, and this was the only sample to exceed the interim maximum acceptable concentrations for drinking water of 0.006 mg L^{-1}.

There were no significant differences in Sb concentrations observed among site types within individual irrigation districts or by site type among the irrigation districts.

For the representative sites, Sb ranged from below detection to 0.0016 mg L^{-1}, with median concentrations ranging from 0.0006 to 0.0009 mg L^{-1}. Greater concentrations were observed in 2006 compared to 2007 (Fig. 37).

Arsenic. Arsenic is a component of some insecticides, lead pipes, and solder. Arsenic can also naturally occur in ground water. It can be either acutely or chronically toxic to humans and other organisms (WHO 2001a).

Arsenic was detected in 92.2% of samples (560 of 607 samples). Detection frequency ranged from 70% in the MID to 100% of samples in six districts (AID, EID, MVID, RID, SMRID, TID). The greatest maximum, mean and median concentrations were observed at the BR-S2 site, at 0.0091 mg L^{-1}, 0.0057 mg L^{-1}, and 0.0057 mg L^{-1}, respectively. Arsenic concentrations exceeded the guidelines for the protection of aquatic life in 2.3 %

of samples, and the livestock watering guidelines in 0.32% of samples, while no samples exceeded the irrigation guideline (CCME 1999). Guideline compliance for the protection of aquatic life threshold was lowest in secondary sites in the BRID (89.7%) and SMRID (90.5%) (Fig. 38).

Arsenic concentrations were significantly different among site types in five irrigation districts (LNID, RID, TID, UID, and WID) (Table 25). In all of these districts, arsenic concentrations were greater in return flows than in primary and secondary sites (Fig. 39).

There were also significant differences among the primary and secondary sites among the districts. Among secondary sites, the SMRID had significantly greater concentrations than the EID and WID, while among the primary sites, the AID, TID, and WID had significantly greater concentrations than the UID (Fig. 39).

For the representative sites, As concentrations ranged from below detection to 0.0016 mg L^{-1}. No samples exceeded guidelines for the protection of aquatic life, livestock watering or irrigation. Arsenic concentrations were greatest in the summer of 2006 (Fig. 40).

Greenlee et al. (2000) reported mean As levels of 0.0007 to 0.0028 mg L^{-1} in portions of the BRID and 0.0005 to 0.0070 mg L^{-1} in the LNID, and reported compliance rates ranging from 83 to 100% with the current drinking water guideline. These concentrations and compliance rates were similar to those observed in the same irrigation districts in our study. As in our study, Greenlee et al. (2000) also did not find any significant differences between block inflow and outflow concentrations in either of the irrigation districts.

Barium. Barium (Ba) is a naturally-occurring substance, and can be released by combustion of fossil fuels and coal. It is ubiquitous in the aquatic environment, with higher concentrations found in waters with greater alkalinity. Although it can be toxic and has been used as an insecticide and rodenticide, there are no water quality guidelines (WHO 1990).

Barium was detected in all but one of the 634 samples, with the greatest concentration of 0.217 mg L^{-1} measured at the MV-R1 site.

There were significant differences in Ba concentrations within three of the irrigation districts (Table 26). Within the WID, return flows had significantly greater Ba concentrations than secondary or primary sites, while LNID return flows were only significantly greater than primary sites. In the TID, primary sites had greater Ba concentrations than either return flow or secondary sites (Fig. 41).

Among primary sites, Ba concentration was greatest in the UID and was significantly greater than the TID, LNID, SMRID, BRID, EID, and WID (Fig. 41). The lowest concentrations were observed in the WID primary sites, which were significantly lower than all other sites except for the EID. For the secondary sites, the UID had significantly greater Ba concentrations than all other sites, followed by the SMRID, which had significantly greater Ba concentrations than most of the remaining sites, except for the

LNID. The EID and WID secondary sites had similar concentrations that were significantly lower than all other sites. Among return flow sites, the UID again had the greatest Ba concentrations, but they were not significantly different from the MVID, AID, RID, and MID return flows. The lowest concentrations were observed in the BRID and EID return flow sites, which were significantly different from most sites except for the TID and WID return flow sites (Fig. 41).

Barium concentrations were similar among the representative sites (Fig. 42). In both study years, concentrations increased at the end of the irrigation season, while in 2006, there were elevated concentrations in June and July.

Boron. Boron (B) can be toxic to crops; however, it is more of an issue when ground water is used for irrigation as surface waters are generally low in B (Ayers and Westcot 1994). Boron is an essential crop nutrient and is occasionally applied as fertilizer to canola and sugar beets.

Boron was detected in 20.4% (125/607) of samples, with detection frequencies ranging from 12.5% in the EID and TID to 31.2% in the AID. The greatest detection frequencies among primary sites were observed in the LNID and RID, with a detection frequency of 28.6% (Fig. 43). The greatest detection frequencies for both secondary and return flow sites were found in the MID (40.0% and 42.9%, respectively).

Concentrations ranged up to 0.49 mg L^{-1} at the M-R1 site. The greatest mean concentrations were also observed at the M-R1 site (0.14 mg L^{-1}), while median concentrations were below detection at all sites. No samples exceeded the guidelines for irrigation or livestock watering.

There were no significant differences in boron concentrations within the irrigation districts or by site types among the irrigation districts (Table 27, Fig. 44).

There were also no significant differences in boron concentrations among the representative sites, with maximum concentrations ranging from below detection to 0.21 mg L^{-1} and with all sites having the same median value (0.025 mg L^{-1}). Boron was only detected in 2006, most commonly in June and July (Fig. 45).

Copper. Copper (Cu) is a common metal that is not very soluble in water and resists corrosion. It can be used as an algicide or bactericide, and has many agricultural applications, including being a component of fertilizers, as growth promoters, feed additives, and for disease prevention in livestock and poultry. It is an essential plant nutrient that can be readily accumulated to toxic concentrations in aquatic and terrestrial plants, as well as fish and aquatic invertebrates; however, tolerance varies widely (WHO 1998).

Copper was detected in 26.8% (163/607) of samples, with a maximum concentration of 0.083 mg L^{-1} observed at the M-P1 site. Detection frequency varied widely, from 5.0% in the EID return flows to 92.6% in the RID return flows. Most sites had a greater

detection frequency in return flows compared to primary sites, with the exception of the AID and EID. Hardness-dependent Cu guidelines for the protection of aquatic life were exceeded in 26 samples. Compliance with guidelines was lowest in the LNID return flows (57.8%) and WID return flows (62.6%), with all other categories having compliance rates in excess of 80% (Fig. 46).

Copper concentrations were greater in return flows compared to primary and secondary sites in the LNID, RID, UID, and WID (Fig. 47, Table 28). There were no significant differences in source water Cu concentrations amongst districts. There were significant differences in return flow sites among the irrigation districts, with the WID and LNID having significantly greater Cu concentrations than most other districts except RID (Fig. 48).

In the representative sites, Cu was detected in 45.8% of samples, with a maximum concentration of 0.024 mg L^{-1}. Three samples exceeded the guidelines for the protection of aquatic life (CCREM 1987). Concentrations were similar for most of the study duration until a peak in September 2007 (Fig. 48).

Greenlee et al. (2000) reported mean Cu concentrations ranging from 0.0016 to 0.0050 mg L^{-1} in the BRID and between 0.001 and 0.007 mg L^{-1} in the LNID. Similar levels of compliance were observed in the two studies.

Iron. Iron (Fe) is a required plant nutrient that can have deleterious effects on aquatic plants and insects. Low levels are recommended for drip or micro-irrigation systems as greater Fe concentrations can cause blockages in irrigation equipment (Peterson 2000). Iron can also have toxic effects on crops or cause unsightly deposits on leaves from sprinkler irrigation (Ayers and Westcot 1994).

Iron was detected in all samples, with concentrations ranging from 0.013 mg L^{-1} at the E-R5 site to 6.32 mg L^{-1} at the LN-R1 site. The highest mean and median samples were also found at the LN-R1 site (3.27 mg L^{-1} and 3.11 mg L^{-1}, respectively). The protection of aquatic life guideline (CCREM, 1987) was exceeded in 157 of 606 samples, or 25.9%, while irrigation guidelines were exceeded by only one sample at LN-R1. Compliance with the protection of aquatic life guideline ranged from 33.3% in the RID to 92.7% in the EID. Among primary sites, the AID compliance rate (25%) was much lower than the remaining primary sites, which were all 75% or above (Fig. 49). Compliance among secondary sites ranged from 59.4% in the WID to 100% in the EID and UID. Return flow compliance ranged widely, from 0% in the RID to 87.5% in the EID and TID.

There were significant differences among the site types in all irrigation districts except for the SMRID and TID (Table 29, Fig. 50). Return flows had significantly greater Fe concentrations than primary and secondary sites (where present) in the BRID, EID, LNID, MID, MVID, RID, UID, and WID (Fig. 50). Secondary sites in the WID also had significantly greater Fe concentrations than primary sites. Conversely, primary sites had significantly greater Fe concentrations than return flows in the AID.

There were significant differences among irrigation districts for each site type. For primary sites, AID had significantly greater Fe concentrations than all other sites except for the EID (Fig. 50). Iron concentrations in the EID were significantly greater than in all other irrigation districts, except the MID. For the secondary sites, the WID, LNID, and SMRID had significantly greater Fe concentrations than other secondary sites. Iron concentrations were significantly greater in LNID, UID, WID, RID, and MID return flow sites compared with BRID, TID, and EID return flow sites (Fig. 50).

There were no significant differences among the representative sites, which had Fe concentrations ranging from 0.03 to 12.9 mg L^{-1} and mean concentrations ranging from 0.24 to 0.94 mg L^{-1}. Iron concentrations also showed no seasonal pattern (Fig. 51). Concentrations at the upstream pipeline site were consistently low, whereas at the downstream site (S3-PL2), there was one outlier, possibly due to an internal source. Guidelines for the protection of aquatic life were exceeded by 31.8% (32/142) samples, while irrigation guidelines were exceeded by one sample (0.8%).

Lead. Sources of lead in the aquatic environment include combustion of coal, oil, and fuels with added Pb. Lead shot and fishing lures are also sources. Lead is not readily soluble and is mostly precipitated out of solution; however, it is more available in acidic water. It can have toxic effects, particularly on young fish (WHO 1989). It is also toxic to humans, with the major sources being from Pb paint and Pb pipes (WHO 1989).

Lead was detected in 41.4% (251/607) of samples. Detection frequency ranged from 12.5% in the TID to 87.5% in the AID. Lead was more frequently detected in return flows in most irrigation districts, except for the AID and EID, where Pb was detected in 100% and 75% of primary site samples, respectively (Fig. 52). The greatest concentrations were observed at the LN-R1 site, with a mean concentration of 0.0017 mg L^{-1} and a maximum concentration of 0.0033 mg L^{-1}, which was one of only two samples to exceed the guideline for protection of aquatic life (CCREM 1987).

There were significant differences in Pb concentration among the site types in eight irrigation districts (Table 30). Return flows had significantly greater Pb concentrations than primary and secondary sites (where present) in the LNID, MVID, RID, TID, UID, and WID (Fig. 53). In addition, WID secondary sites had significantly greater Pb concentrations than primary sites. Conversely, primary sites had significantly higher Pb concentrations than return flow sites in the AID and EID.

There were also significant differences in Pb concentrations among the irrigation districts for all site types (Fig. 53). Among primary sites, the EID had significantly greater Pb concentrations than most sites except AID, MID, and WID. The EID, AID, and WID primary sites were also significantly greater than the UID, BRID, and TID. Among secondary sites, the WID had significantly greater concentrations than all other secondary sites whereas the LNID secondary sites had significantly greater Pb concentrations than the EID and TID secondary sites. The LNID, UID, and RID return flow sites had significantly greater concentrations than return flows in the SMRID, AID, BRID, EID, and TID.

Lead was detected in more than half (67/132) of the representative samples, including all SMC-R4 samples. Mean concentrations ranged from 0.00012 to 0.00029 mg L^{-1}, with a maximum observed concentration of 0.0012 mg L^{-1} (Fig. 54). Concentrations at the secondary source site (SMC-S3) were significantly greater than those at the downstream pipeline site (SMC-PL2).

Greenlee et al. (2000) reported only infrequent detections of Pb, with all block outflow samples meeting guidelines for the protection of aquatic life.

Lithium. Lithium (Li) is not required for plant growth, but small amounts can stimulate plant growth. It can be toxic to certain plants, especially citrus trees and cool season grasses (Sneva 1979). Lithium uptake is greater in acidic soils. It does not tend to bioaccumulate in animals. It is used in pharmaceuticals and batteries, the improper disposal of which can result in environmental contamination (Aral and Vechhio-Sadus 2008).

Lithium was detected in 12.8% (78/607) of samples. By far the greatest detection frequency was in the BRID where Li was detected in 54% of samples (Fig. 55); however, none of the Li concentrations ever exceeded water quality guidelines (CCREM, 1987). The greatest mean (0.304 mg L^{-1}), maximum (0.05 mg L^{-1}) and median (0.03 mg L^{-1}) concentrations were observed at the BR-S2 site. Lithium was not detected at 15 sites and there were no detections of Li in the AID.

Lithium concentrations were significantly different among the site types within three irrigation districts (Fig. 56, Table 31). Return flows had higher concentrations than primary sites in the MID, SMRID, and WID. Return flow concentrations were also greater than secondary sites in the SMRID and WID.

Among the primary sites and secondary sites, the BRID had significantly greater Li concentrations than all other sites of the same type (Fig. 56). The BRID and WID return flow sites had significantly greater Li concentrations than the remaining districts.

Lithium was detected in 5.7% (8/139) of representative samples, with a maximum concentration of 0.020 mg L^{-1}. There were no differences among the sites and no consistent seasonal pattern (Fig. 57).

Manganese. Manganese (Mn) can be toxic to plants, but greater amounts are generally absorbed from acidic or poorly aerated soils, conditions that are not common in our study area. Manganese can also cause obstructions in irrigation nozzles; therefore, Ayers and Westcot (1994) recommended a maximum concentration of 0.1 mg L^{-1}, the CCME irrigation guideline is 0.2 mg L^{-1} (CCREM 1987) while Health Canada has an aesthetic objective of 0.05 mg L^{-1} for drinking water.

Manganese was detected in nearly all of the samples (631/633). The greatest mean (0.10 mg L^{-1}) and maximum (0.221 mg L^{-1}) concentrations were found at the SME-S1 site,

while the greatest median value was found at the LN-R1 site (0.09 mg L^{-1}). The lowest mean concentrations were observed at the AEP-P1 and U-P1 sites (0.002 mg L^{-1}). Irrigation guidelines were exceeded by two samples in the SMRID.

There were significant differences among site types within eight irrigation districts (Table 32), with return flows having significantly greater Mn concentrations than primary and secondary sites in the AID, BRID, LNID, MID, RID, TID, UID, and WID (Fig. 58). Secondary sites had significantly greater Mn concentrations than primary sites in the TID.

There were also significant differences by site type among the irrigation districts. Among the primary sites, the MVID had significantly greater Mn concentrations than all other districts. For the secondary sites, the SMRID had significantly greater concentrations than LNID, BRID and UID. Among the return flow sites, the LNID had the greatest Mn concentration, which was significantly greater than those in the SMRID, TID, BRID, MVID, EID, and AID. Return flows in the WID also had significantly greater Mn concentrations than the BRID, EID, MVID, and AID (Fig. 58).

Manganese was detected in all 146 representative samples, with one sample exceeding the irrigation guideline. Mean concentrations ranged from 0.014 to 0.028 mg L^{-1}, but there were no significant differences among sites, with maximum values observed early in the irrigation season (Fig. 59).

Nickel. Nickel (Ni) is widely distributed in the environment through natural (atmospheric deposition of eroded sediment, forest fires) and anthropogenic (metallurgic and chemical industry, combustion of fossil fuels, food processing, tobacco smoke) sources. Contamination of water is mostly through domestic wastewater or metal smelting (Cempel and Nikel 2006). Nickel can bioaccumulate in aquatic organisms, particularly in phytoplankton (Cempel and Nikel 2006).

Nickel was detected in 16.1% (98/607) of samples. Nickel was generally more frequently detected in return flows compared with other site types, except in the AID, TID and the SMRID, which also had among the lowest detection frequencies among the irrigation districts (Fig. 61). The maximum concentration of 0.009 mg L^{-1} was observed at the LN-R1 and SMC-P1 sites, and was below water quality guidelines for irrigation and protection of aquatic life (CCREM 1987). Mean concentrations were greatest at the LN-R1 site (0.0044 mg L^{-1}), while 34 sites had mean concentrations below detection limits.

As there were few detections, there were also few differences among site types within the irrigation districts. There were significantly greater Ni concentrations in return flows compared with primary and secondary sites in the LNID, UID, and WID (Fig. 61, Table 33). There were no differences among irrigation districts primary site Ni concentrations. There were significant differences among secondary sites, with greater Ni concentrations in the BRID compared to the SMRID. Among return flow sites, the WID had significantly greater Ni concentrations compared to return flows in all other irrigation

districts, while the LNID return flows had significantly greater Ni concentrations than most of the remaining irrigation districts, except MID and UID (Fig. 61).

Detection frequencies for Ni in the representative samples were 15.1% (21/139), with a maximum concentration of 0.008 mg L^{-1}. There were a greater number of detections in 2007 compared to 2006 (Fig. 62).

Selenium. Selenium (Se) is an essential nutrient that is found in association with high-sulphur coals and sulphur-containing minerals; however, it can also be toxic to humans and wildlife (Lenz and Lens 2009). Selenium, which has been mobilized from weathering marine sedimentary rocks and seleniferous soil and concentrated in subsurface irrigation runoff, has been a major issue in the Imperial Valley and San Joaquin Valley of California, where it has been linked to deformities in seabird populations of the Kesterton Reservoir (Engberg et al. 1998). As Se readily bioaccumulates and biomagnifies, concentrations in animal tissues can be up to 4000 times greater than those in water. Due to the high concentrations in tissues relative to water, the US EPA (2008) has recommended chronic guidelines be based on fish tissue concentrations rather than ambient nutrient concentrations.

Selenium was detected in 69.0% (419/607) of the samples. Detection frequencies within the irrigation districts ranged from 34.4% in the UID to 95.3% in the WID. The greatest mean concentration was observed at the R-R1 site (0.0021 mg L^{-1}), while the greatest maximum concentration was observed at the LN-R1 site (0.010 mg L^{-1}). Selenium exceeded guidelines for the protection of aquatic life (0.001 mg L^{-1}, CCREM 1987) in 12.8% of samples; however, irrigation guidelines were never exceeded. The lowest compliance rate was found in the MID return flows (28.6%) (Fig. 63).

Significant differences among site types within the irrigation districts were only observed in the MID, where Se concentrations were significantly greater in return flow sites compared with primary sites (Fig. 64, Table 34).

There were significant differences among the irrigation districts for each site type (Table 34). Among primary sites, Se concentrations in the WID were significantly greater than the TID, SMRID, AID, MVID, and UID (Fig. 64). Secondary sites in the LNID had significantly greater Se concentrations than the EID, TID, UID, and SMRID. Return flow sites showed a different pattern, with concentrations in the MID and RID significantly greater than most other irrigation districts, except for the WID.

Selenium was detected in 81.6% (102/125) of the representative samples, with a maximum concentration of 0.0021 mg L^{-1}. Twelve samples exceeded the guideline for the protection of aquatic life. There were no seasonal patterns or differences among the sites (Fig. 65).

Thallium. Thallium (Tl) is ubiquitous at low concentrations in the environment. In the past, it was used as an insecticide and rodenticide, but its use for these purposes is now restricted (WHO 1996).

Thallium was detected in 34 of the 607 samples (5.6%). The greatest detection frequencies were observed in the WID (15.6%) and in the EID (14.5%), especially in primary sites, with the remaining irrigation districts having detection frequencies below 10% (Fig. 66). The greatest mean and maximum Tl concentrations were observed at the E-S2 site, at 0.00031 and 0.0021 mg L^{-1}, respectively. Three samples, one each from an EID secondary, an LNID secondary, and a WID return flow, exceeded the guideline for the protection of aquatic life (0.0008 mg L^{-1}, CCME 1999).

Significant differences among site types were only observed in the WID, where return flows had significantly greater concentrations than primary and secondary sites (Table 35). Among return flow sites, the WID had significantly greater Tl concentrations than all other irrigation districts (Fig. 67).

The thallium detection frequency for the representative sites was 10.3% (15/146), with a maximum concentration of 0.0008 mg L^{-1} (Fig. 68).

Titanium. Titanium (Ti) is a relatively common element in the lithosphere. It readily complexes with oxygen; therefore, Ti does not exist in its metallic state naturally. It is used in the aerospace industry, in biomedical devices, paints and pigments, and in nanotechnology. It is not required for human or animal growth, is poorly absorbed by plants, and is not toxic (WHO 1982). There are no water quality guidelines for titanium.

Titanium was detected in 84.2% (511/607) of the samples. Detection frequencies ranged from 64.6% of EID samples to 100% of AID and RID samples. The greatest mean (0.098 mg L^{-1}) and maximum (0.141 mg L^{-1}) concentrations were observed at the LN-R1 site.

There were significant differences among site types within four irrigation districts (Table 36). Return flow Ti concentrations were significantly greater than primary and secondary sites (where present) in the LNID, RID, UID, and WID (Fig. 69).

There were no significant differences among the districts in Ti concentrations from the primary sites. There were significant differences among secondary sites and among return flow sites. The LNID secondary sites had greater Ti concentrations than the EID and TID secondary sites. Among return flows, Ti concentrations were significantly greater in the LNID compared to most other districts and significantly lower in the TID and EID compared to most other districts (Fig. 70).

For the representative sites, Ti concentrations were detected in a greater proportion of samples (94.6% or 125/132) than in the comprehensive study. The maximum observed concentration was 0.071 mg L^{-1}, with mean values ranging from 0.010 to 0.017 mg L^{-1}. Greater concentrations were generally observed in June through August, particularly in 2006 (Fig. 70).

Uranium. Uranium (U) is extremely toxic to humans and other animals. The main source of U contamination is a result of mining operations; however, U can also be an

impurity in P fertilizers that can be mobilized from soils, particularly acidic soils (Yamaguchi et al. 2009).

Uranium was detected in all samples. Concentrations ranged from 0.0002 mg L^{-1} at five sites (AEP-P1, AEP-S1, AEP-S2, MV-P1, U-P1) to 0.0053 mg L^{-1} at the AEP-P2 site. The greatest mean concentration was observed at the BR-R3 site (0.0022 mg L^{-1}). All of the samples complied with the guideline for irrigation (0.010 mg L^{-1}, CCREM 1987).

There were significant differences among site types within six irrigation districts (Table 37). Return flows had significantly greater U concentrations than primary and secondary sites in the LNID, MID, RID, TID, WID, and UID (Fig. 71). In the EID, return flow concentrations were only significantly greater than secondary sites, while in the LNID and UID, secondary sites had greater U concentrations than primary sites.

There were also significant differences among the irrigation districts by site type (Table 37). Among primary sites, U concentrations were greatest in the WID and were significantly greater than all other irrigation districts, followed by the MID and BRID, which were also significantly different from all other primary sites (Fig. 71). Uranium concentrations in primary sites from the UID, MVID, and AID were significantly lower than all other district primary sites. The BRID and WID secondary sites had similar concentrations that were significantly greater than all other district secondary sites. The TID and SMRID also had greater concentrations than the remaining secondary sites. The WID return flow sites had significantly greater U concentrations than nearly all other districts, except for the MID.

Uranium concentrations in the representative sites ranged from 0.0005 to 0.0017 mg L^{-1}. Concentrations were greatest at the beginning of the irrigation season then declined to minimum values in late August or early September before increasing slightly for the last few samples (Fig. 72). There were no differences among sites.

Vanadium. Vanadium (V) is not an essential nutrient for plant development; however, it causes damage to a wide range of crops at low concentrations causing iron-deficient chlorosis or by affecting trace element nutrition. Fertilizers and sewage sludge are potential sources of V (WHO 1988).

Vanadium was detected in 30% (182/607) of the samples. Vanadium was detected least frequently in the EID return flow sites (10%) and most frequently in the RID return flow sites (100%). Vanadium was more frequently detected in return flows, except for in the EID, where primary sites had the greatest detection frequency (Fig. 73). The maximum concentration (0.0097 mg L^{-1}) was observed at the LN-R1 site. Concentrations never exceeded water quality guidelines for irrigation (0.100 mg L^{-1}, CCREM 1987).

Within the individual irrigation districts, there were significant differences among site types in eight irrigation districts (Table 38). In the EID, there were significantly greater V concentrations in the primary sites compared with the secondary and return flow sites

(Fig. 74). In six districts (LNID, MID, MVID, RID, UID, and WID), V concentrations were significantly greater in return flows compared to primary sites.

There were significant differences in V concentrations among irrigation districts for all three site types (Table 38, Fig. 74). Primary sites in the AID had significantly greater V concentrations than nearly all other districts, except for the EID. The WID secondary sites had significantly greater concentrations than EID secondary sites. Return flow sites in the LNID and UID had significantly greater V concentrations than most other districts except for the WID, RID, and MID. The WID and RID return flows had significantly greater concentrations than the SMRID, BRID, TID, and EID return flows, while the MID had significantly greater concentrations than the EID return flows.

For the representative sites, V was detected in 25.8% (34/132) samples, with a maximum concentration of 0.005 mg L^{-1}. Peak concentrations were observed during July or August (Fig. 75). There were significantly greater concentrations of V in SMC-S3 than at the SMC-E3 site (Fig. 75).

Zinc. Sources of zinc (Zn) in the environment include forest fires, igneous emissions, and erosion of Zn-bearing sediments. Anthropogenic sources include fossil fuel combustion, Zn-bearing fertilizers and pesticides, fungicides, mining, and industrial processes. Zinc is essential for survival and many crops can be deficient in Zn; however, at higher concentrations it may be toxic to terrestrial and aquatic organisms. Many factors affect the bioavailability and toxicity of Zn, and therefore, water concentrations alone may not be a reliable indicator (WHO 2001b).

Zinc was detected in 74.1% (450/607) of samples, with the greatest detection frequency in the AID (93.8%) and the least in the MID (65.9%). Greater detection frequencies were observed in the return flows, except for in the EID and UID (Fig. 76). The maximum concentration was observed at the W-S3 site (0.20 mg L^{-1}), which also had the greatest mean concentration (0.032 mg L^{-1}). Sixteen samples (2.6%) in seven of the districts exceeded the guideline for the protection of aquatic life, while the irrigation guideline was never exceeded (CCREM 1987). In the BRID, EID, MID, and WID, primary samples exceeded the protection of aquatic life guideline, while in the LNID, TID, UID, and WID secondary samples exceeded this guideline. Return flow samples in the EID, LNID, TID, UID, and WID exceeded the protection of aquatic life guideline.

There were few differences among site types within two of the irrigation districts (Table 39). In the BRID, return flow sites had significantly greater Zn concentrations than secondary sites, while primary sites in the EID had significantly greater Zn concentrations than return flow sites (Fig. 77).

Among return flow sites, the LNID and UID had significantly greater Zn concentrations than the SMRID (Fig. 77). There were no differences among primary or secondary sites in the various districts.

For the representative sites, Zn was detected in 80.3% (106/132) of samples, with a maximum concentration of 0.172 mg L^{-1}. Ten samples exceeded guidelines for the protection of aquatic life. Peak concentrations were observed in May, particularly in 2006, and tended to decrease throughout the irrigation season (Fig. 78).

Bacteria and Physical Variables

Mean values for the bacteria and physical variables for the irrigation districts by site type can be found in Table 40.

Total Coliforms. Bacteria were enumerated using the most probable number (MPN) method, and the upper limit for total coliforms was 4840 MPN 100 mL^{-1}. More than half of the samples exceeded this value. Total coliform compliance with irrigation guidelines (1000 MPN 100 mL^{-1}, CCREM 1987) ranged from 23.4% in the WID to 60.4% in the MID (Fig. 79), while overall compliance was 43.8% (356 of 634). All districts had lower compliance in return flows compared to primary sites.

There were significant differences in total coliform counts among site types in five irrigation districts (Fig. 80, Table 41). Return flow site total coliform concentrations were significantly greater than primary sites in the BRID, EID, LNID, RID, and UID. Return flow concentrations were also significantly greater than secondary concentrations in the BRID, EID, LNID, and UID. Differences may have been masked by the large number of samples that exceeded the limits of detection.

There were significant differences among primary sites and among secondary sites. The WID primary sites had significantly greater total coliform counts than the LNID, BRID, and UID primary sites (Fig. 80). The AID, MID, SMRID, and TID primary sites also had significantly greater total coliform counts than the UID primary site. For the secondary sites, the WID was significantly greater than the EID, LNID, and UID. The TID secondary sites had significantly greater total coliform concentrations compared with the EID and UID sites. Significant differences could not be determined among return flow sites as most return flow samples exceeded the upper detection limits for total coliform values.

For the representative sites, 43.2% (63/146) of samples exceeded the CCME guideline for irrigation. There were significant differences among sites, with increasing total coliforms observed moving downstream through the earthen canal (Fig. 81). Significantly greater total coliforms were observed at the return flow site (SMC-R4) and the downstream end of the earthen canal (SMC-E3) than the remaining sites, except for the SMC-E2 site. Concentrations at the two pipeline sites and the upstream earthen canal site (SMC-E1) tracked each other, with slightly lower concentrations at the downstream pipeline site (SMC-PL1). It was difficult to detect seasonal trends due to the frequent exceedances of the upper detection limit.

Escherichia coli. *Escherichia coli* (*E. coli*) is an indicator of the presence of animal-borne enteric pathogens (i.e., fecal contamination), and thus indicate that harmful bacteria

or viruses may be present. *Escherichia coli* is a more specific indicator than total or fecal coliforms; however, the majority of fecal coliforms are *E.coli* and therefore, comparisons to the fecal coliform irrigation guideline were included.

The recreation guidelines for *E. coli* (Alberta Environment 1999) were exceeded in 14.5% (92/634) of samples. Compliance ranged from 58.3% in the RID to 93.8% in the EID. Compliance was generally lowest in return flow samples, except in the AID and TID (Fig. 82). The irrigation guidelines for fecal coliforms (CCREM 1987) were exceeded in 26.6% (169/634) of samples. Compliance with the irrigation guidelines in primary sites ranged from 50% in the TID to 100% in three districts, while among the secondary sites, compliance ranged from 56.2% in the WID to 100% in the UID. The lowest compliance was observed in the LNID and RID return flows (12.5%); however, all districts had some incidences of non-compliance in the return flows and nearly all, except for the TID, had the lowest compliance in the return flows. As with total coliforms, many samples exceeded the limits of detection.

There were significant differences in *E. coli* counts between primary, secondary and return flow sites in all but the AID and TID, as these two districts had relatively high *E. coli* concentrations in their primary sites (Table 42, Fig. 83). The remaining districts all had significantly greater *E. coli* concentrations in return flows compared to primary sites. Secondary sites also had significantly lower concentrations than in return flows, except for in the WID. The EID and UID secondary sites had significantly lower concentrations of *E. coli* than primary sites, while the BRID and WID secondary sites had significantly greater *E. coli* concentrations than primary sites.

There were significant differences in *E. coli* concentrations among each of the site types (Fig. 83). The greatest concentrations were in the AID primary sites, which were significantly greater than the SMRID, WID, BRID, and MVID. The TID and UID had the next greatest *E. coli* concentrations and were significantly greater than the BRID and MVID. The LNID, MID, and EID primary sites also had significantly greater *E.coli* concentrations than the MVID primary site. Among secondary sites, the greatest concentrations were found in the WID and TID, which were significantly greater than all other secondary sites. The LNID secondary site also had significantly greater *E. coli* concentrations than the EID and UID. There were significantly greater *E. coli* concentrations in the RID and LNID return flows compared to the EID, SMRID, and TID, while the WID also had significantly greater *E. coli* concentrations than the TID return flows.

For the representative sites, seven of the 146 samples (4.8 %) exceeded the recreation guideline (200 MPN 100 mL^{-1}) and 12 of the 146 samples (8.2%) exceeded the fecal coliform irrigation guideline. *Escherichia coli* concentrations followed a similar pattern as total coliforms with significantly greater concentrations at the SMC-R4 and SMC-E3 sites than at all the other sites. The SMC-E2 and SMC-S3 sites had similar *E. coli* concentrations that were significantly greater than the upstream earth canal site (SMC-E1) and the pipeline sites (SMC-PL1, SMC-PL2). Concentrations at the SMC-E3 site

were greater in 2006 than in 2007, with peaks in June and September, while the maximum concentrations in 2007 were observed at the SMC-R4 site in July (Fig. 84).

Most previous studies in the irrigation districts have used fecal coliforms as a bacterial indicator, rather than total coliforms or *E. coli*; therefore, results are not directly comparable. Nonetheless, increases in bacterial indicators commonly occur between source waters and return flow sites (Madawaska Consulting 1997; Greenlee et al. 2000).

Total Suspended Solids. The CCME guidelines for the protection of aquatic life are based on an increase above background levels (CCME 1999), and therefore were not directly comparable in our study. Total suspended solids (TSS) can negatively impact fish spawning habitat and clog irrigation equipment. Total suspended solids can also be a source of contaminants such as metals, nutrients, and bacteria.

Total suspended solids concentrations ranged from below detection at several sites to 164 mg L^{-1} at the LN-R1 site. The greatest mean (88.8 mg L^{-1}) and median (81.5 mg L^{-1}) values were also detected at the LN-R1 site, which had three of the four greatest values observed. Only one other site had a maximum value greater than 100 mg L^{-1}, with the rest having maximum values below 70 mg L^{-1}. Seventeen sites had median values below detection, while three sites had maximum values below the detection limits (AEP-P1, BR-R5 and E-R5).

There were significant differences among site types within six irrigation districts (Table 43, Fig. 85). For the LNID, MID, RID, and UID, there were significantly greater TSS concentrations in return flows; however, in the AID and EID there were significantly greater TSS concentrations in the primary sites (Fig. 85). In the EID, this was likely due to the relatively low TSS concentrations in the return flows, rather than elevated concentrations in the primary sites, whereas this combination of factors contributed to the differences in the AID. Greater TSS concentrations in return flows are not surprising given that many of our primary source sites were immediately downstream of reservoirs or from channels with stabilized banks.

Among the primary sites, the AID had the greatest concentrations that were significantly greater than the MVID, MID, BRID, TID, and UID (Fig. 85). The WID had TSS concentrations that were significantly greater from most of the same sites, with the exception of the MVID. For the secondary sites, the greatest TSS concentrations were found in the SMRID, which were significantly greater than secondary sites in the BRID, TID, EID, and UID. The WID had the second greatest TSS concentrations in the secondary sites and was significantly greater than the TID, EID, and UID secondary sites. For return flow sites, the greatest concentrations were found in the LNID, RID, UID, and WID. These sites had significantly greater concentrations than the SMRID, MVID, BRID, TID, AID, and EID. The MID return flows also had significantly greater TSS concentrations than the BRID, TID, AID, and EID, while the SMRID had significantly greater TSS concentrations than the EID.

The high concentrations of TSS in the AID primary sites were likely due to its position close to the mountain headwaters. In the WID primary sites, greater sediment loads could be related to high sediment loads from the City of Calgary. The greatest changes were observed in the LNID. There were also large changes between the primary and return flow sites in the MID, RID, and UID. Similar to our study, a review of water quality in six irrigation districts reported greater TSS concentrations in LNID (Madawaska Consulting 1997); however, they also found greater TSS concentrations in TID return flows. Changes in irrigation practices and infrastructure may have reduced erosion in the TID canals, while increased flows at the LN-R1 site may have increased erosion in this natural drain.

For the representative sites, there were no significant differences in TSS concentrations and no clear patterns. The two greatest values were observed at the two pipeline sites, and this finding was unexpected (Fig. 86).

pH. The pH exceeded the CCME water quality guideline for the protection of aquatic life (CCREM 1987) in 49 of the 634 samples (7.7%). The pH ranged from 6.9 at the E-P1 and W-S2 sites to 9.9 at SMC-R2 and SMC-R3. Guidelines were most frequently exceeded in TID secondary sites (34.8%) and SMRID return flows (29.1%), while guidelines were always met in four districts (AID, MVID, MID, and RID) (Fig. 87).

There were significant differences in pH among the site types in two irrigation districts. The BRID had significantly greater pH in secondary sites compared to primary sites, while the SMRID return flows had significantly greater pH than primary or secondary source sites (data not shown).

There were also significant differences among irrigation districts for the secondary and return flows. Among secondary sites, the BRID had significantly greater pH compared to all other districts, while the EID and LNID had significantly greater pH than the TID, UID, and WID. Among return flow sites, the SMRID and TID had significantly greater than the EID, AID, LNID, and RID.

None of the representative samples exceeded the CCME guideline for pH. The pH ranged from 7.2 to 8.8. Values had a much greater range in 2007 compared to 2006 (Fig. 88).

Pesticides

Pesticides were detected in 575 of 634 samples (90.7%). Of the 25 compounds examined, nine compounds, all herbicides, were found: 2,4-D, dicamba, MCPA, dichlorprop, mecoprop, bromoxynil, clopyralid, picloram, and triallate. The most commonly detected herbicides was 2,4-D (90.5%), followed by dicamba (47.0%), MCPA (38.2%), mecoprop (11.8%), and dichlorprop (10.2%) (Fig. 90). The remaining four detected herbicides were found in less than 10% of samples, including triallate, which was found in only one sample (0.16%) (Fig. 89).

The same pesticides were detected in the representative sites, with the exception of picloram, which was not detected at the representative sites. As with the comprehensive sites, 2,4-D was the most commonly detected pesticide (89.4%); however, this was followed by MCPA (68.5%), and then dicamba (46.6%). Dichlorprop was detected in 17.1% of representative samples, while the remaining pesticides were detected in less than 10% of samples.

Detection frequencies for dichlorprop were greater in the representative samples than in the comprehensive samples. Dichlorprop is used in conjunction with 2,4-D for weed suppression in barley and wheat; however, it is also used for industrial applications in road ditches, and right of ways.

The most frequently detected pesticide in our study, 2,4-D, was also the most commonly detected compound in the long-term monitoring of agricultural streams in Alberta (Lorenz et al. 2008). The herbicide is also the second most commonly purchased compound in Alberta (Byrtus 2007). In addition, it was the most frequently detected compound in a study of inflows and outflows in two irrigation districts, the BRID and LNID (Greenlee et al. 2000). Similar to our representative study, Greenlee et al. (2000) and Lorenz et al. (2008) found MCPA was the second most commonly detected compound, with detection frequencies of 54% and 31%, respectively. Dicamba was detected less frequently in the other studies compare with our study, with detection frequencies of 21% in the Greenlee et al. (2000) study and 13% in the Lorenz et al. (2008) study.

Pesticides were detected in all samples from the SMRID, while the BRID, EID, RID, TID, and WID all had detection frequencies greater than 90% (Fig. 91). The lowest detection frequencies were found in MID (48%), UID (62.5%), and MVID (62.5%). It was not possible to statistically determine differences in detection frequency among irrigation districts as the large number of identical numbers did not allow the mixed model to converge.

Detection frequency was generally greater in the return flow sites, followed by the secondary and primary sites (Fig. 90); however, these values could not be evaluated statistically. Detection frequencies in primary sites showed the greatest variability, from 0% in the UID to 100% in three other districts (RID, SMRID, and TID). Five irrigation districts had pesticides detected in 100% of return flow samples (BRID, LNID, SMRID, TID, WID), while MID and MVID were the only districts with return flow detection frequencies below 90%, at 62.5 and 75%, respectively. Lorenz et al. (2008) reported detection frequencies greater than 90% in four irrigation return flow streams in Alberta between 1999 and 2006.

For the representative sites from the SMRID, detection frequencies were very similar, ranging from 90.4% to 100%.

Compliance with Guidelines. The CCME guidelines for the protection of aquatic life (PAL) (CCREM 1987) were exceeded for 2,4-D on four occasions. Three of these

occurred in the WID at site W-S4 in 2007. The fourth was an extremely high value (37.69 µg L^{-1}) reported at SMC-R1 in August 2006. It is uncertain whether this value is accurate as it is greater than double the concentration of the next nearest value and the lab expressed concern regarding the accuracy of this value; therefore, it was considered a detection, but the quantitative value was not used in the analysis.

In contrast, dicamba exceeded the guidelines for irrigation every time it was detected, but did not exceed the guidelines for the protection of aquatic life or livestock watering (CCME 1999) (Fig. 91ii). Similarly, MCPA exceeded irrigation guidelines in 91.5% of the samples in which it was detected, but did not exceed other CCME guidelines for the protection of aquatic life or livestock water (CCME 1999) (Fig. 91i).

Triallate, bromoxynil, and picloram were all well below CCME guidelines. No guidelines exist for the other three compounds detected: clopyralid, dichlorprop, and mecoprop. Mean concentrations are shown in Table 44.

Pesticides per Sample. The maximum number of pesticides per sample was eight in two samples from the WID in June of 2007, including AEP-P2 upstream of Chestermere Lake and W-S4. Seven pesticides were detected in three other samples from the WID on the same date (W-R2, W-S1, W-S3), while six pesticides were detected in a single sample from the W-R2 site in July 2007. The majority of samples contained only one (32.7%) or two (31.0%) detectable pesticides (Fig. 92).

For the representative samples, the maximum number of pesticides per sample was six, detected at the three earth canal sites in June of 2006 (Fig. 92). The median number of pesticides per sample was two; however, there were similar numbers of samples with one (23.3%), two (28.8%), or three (26.7%) detections per sample.

Total Concentrations. Total pesticide concentrations are calculated from the sum of all pesticide concentrations in a sample. However, the actions of pesticides are not additive, and so these values must be interpreted with caution. The greatest total pesticide concentrations were all observed in the WID with the greatest concentrations observed at W-S3 (25.3 µg L^{-1}) and the next two greatest values observed at the W-S4 site (10.3 µg L^{-1} and 7.4 µg L^{-1}).

There were significant differences in total pesticide concentrations in five irrigation districts (BRID, EID, LNID, TID, UID) (Table 45, Fig. 93). Most of them had greater concentrations in the return flow streams.

Among the primary sites, total pesticide concentrations were significantly greater at the WID sites than the other irrigation districts (Fig. 93). The SMRID primary sites also had significantly greater concentrations than the MID, MVID, LNID, and UID primary sites. Total pesticide concentrations at the WID secondary sites were also significantly greater than at all other districts, while total pesticide concentrations at the TID secondary sites were significantly greater than the EID and LNID. Among the return flow sites, total pesticide concentrations were significantly greater in the TID, BRID, and WID compared

with EID, MID, and MVID. The greatest pesticide concentrations observed in the primary and secondary sites were likely due in part to stormwater runoff from the City of Calgary and the community of Chestermere entering the irrigation system.

Concentrations of the most frequently detected pesticide, 2,4-D showed similar patterns as the total concentrations, except there were no significant differences among the site types within the EID (Table 46, Fig. 94). Similarly, concentrations in primary and secondary sites in the WID were significantly higher than primary and secondary sites in all other irrigation districts.

Seasonal Patterns. There were no significant differences among the seven representative sites for any individual pesticide or total pesticide concentrations.

Concentrations of 2,4-D ranged from below detection to a maximum of 3.73 $\mu g\ L^{-1}$ at the SMC-S3 site (Fig. 95). Median concentrations ranged from 0.08 to 0.11 $\mu g\ L^{-1}$. Maximum concentrations were observed in either June or July (Fig. 95). Median dicamba concentrations were below detection at all but two sites: SMC-S3 and SMC-E3. Dicamba concentrations showed a peak in June, with an additional peak in late July observed at the SMC-S3 site in both years (Fig. 96). Concentrations of MCPA showed a similar pattern with peak concentrations observed in June and an additional peak at the SMC-S3 site in July 2006 (Fig. 97). Median MCPA concentrations ranged from 0.024 to 0.034 $\mu g\ L^{-1}$.

Total pesticide concentrations were largely influenced by the 2,4-D concentrations. In 2006, concentrations were elevated throughout the season, whereas in 2007, a more distinct June peak was observed (Fig. 98). The maximum concentration was observed at the SMC-S3 site in July 2007 due to the high 2,4-D concentration.

Alberta Irrigation Water Quality Indices

Irrigation Water Quality Index. The results from the irrigation water quality index suggest that water quality in the irrigation system is mostly good or excellent, particularly in the source waters (Fig. 99). There were 44 sites with an 'excellent' water quality rating, including five of the six Alberta Environment sites upstream of the irrigation districts and eight return flow sites. An additional 32 sites had a 'good' water quality rating, including six primary sites, seven secondary sites and 19 return flow sites. There were two return flows with 'fair' water quality for irrigation (E-R2, W-R2) and one secondary (W-S3) and one return flow (E-R1) with only 'marginal' water quality for irrigation. These lower scores were due to irrigation guideline exceedances of MCPA, dicamba, and bacteria.

For the representative sites, irrigation water quality index scores were fairly similar (Fig. 100) with four sites rated as 'good' (SMC-S3, SMC-R4, SMC-E3, SMC-PL3) and the remaining sites rated 'excellent'.

Protection of Aquatic Life Index. For the protection of aquatic life index, 35 of the sites had 'excellent' water quality, while another 35 had 'good' water quality (Fig. 101). There were eight sites that rated 'fair' and most of the lower ratings were due to exeedances of metals, *E. coli*, and nutrients. The exceptions were the sites W-S3 and W-S4, where exceedances of 2,4-D guidelines also contributed to the lower scores. The lowest water quality index scores were found at the LN-R1 site due to exceedances of most metals as well as TP and *E.coli* and the U-R1 site, due to exceedances of pH, metals and TP. These sites had a rating of 'marginal'.

For the representative sites, all sites ranked 'good', with occasional exceedances of metals and TP guidelines (Fig. 102).

SUMMARY AND CONCLUSIONS

Comprehensive Study

The following conclusions are based on the comprehensive sampling of 79 sites in 2006 and 80 sites in 2007.

Principal Components Analysis. The BRID and WID had greater ionic, nutrient and pesticide concentrations in comparison with the MVID, UID, and AID. In general, return flow sites also tended to have greater ionic, nutrient, and pesticide concentrations, especially compared to other site types within their districts. It is interesting to note that these parameters tend to be lower in the mountain districts and greater in the districts that are downstream of urban centers.

The LNID, RID, and UID sites had greater metal, bacteria, and TSS concentrations in comparison to the BRID, EID, and SMRID source water sites, which had lower concentrations. Potentially, cow-calf access may explain the greater bacteria and total suspended solids.

Nutrients. The TP guideline for the protection of aquatic life was exceeded in 22% of the 634 samples. Guideline compliance was greatest in AID (100%) and least in RID (50%) and WID (69%). Total P concentrations ranged from below detection to a maximum of 0.54 mg L^{-1}. Five irrigation districts (LNID, RID, SMRID, TID, and UID) had significantly greater TP concentrations in return flow compared to source water. Dissolved reactive phosphorus concentrations ranged from below detection to a maximum of 0.31 mg L^{-1}. Three irrigation districts (LNID, RID, and UID) had significantly greater concentrations of DRP in return flow compared to source waters, while the remaining eight districts showed no differences in DRP among site types. There were more changes noted in TP concentrations compared to DRP concentrations in some districts (SMRID and TID), suggesting that particulate P sources may need to be addressed. Sources of particulate P may include bank erosion from high flows or livestock access.

The TN guideline for the protection of aquatic life was exceeded in about 7% of the 634 samples. Guideline compliance was 100% in five districts (AID, LNID, MVID, RID, and UID) and greater than 80% in the remaining six districts. Six irrigation districts (LNID, MID, SMRID, TID, UID, and WID) had significantly greater TN and TKN concentrations in return flow compared to primary source water. In contrast, the EID showed significantly higher TN concentrations in primary source water compared with return flow. The EID primary source water had significantly higher TN concentrations than most other districts except for the MVID. It should be noted that these conclusions are based on one primary site from EID, but these findings are similar to previous studies.

The NO_3-N guideline for the protection of aquatic life was always met as was the NO_3+NO_2-N guideline for livestock watering. The NO_3-N concentrations showed different trends than the TN and TKN concentrations. Four districts (EID, LNID, RID, and UID) had significantly greater NO_3-N concentrations in primary source water than return flow, with the decreases attributable to denitrification.

The NO_2-N guideline for the protection of aquatic life was nearly always met (>99% compliance). Significant differences in NO_2-N concentrations were observed in two districts. In the LNID, greater concentrations were found in primary source water compared with return flow, while in the WID, greater NO_2-N concentrations were found in return flow compared to source water.

The NH_3-N guideline for the protection of aquatic life was almost always met (less than 1% of samples exceeded). Significant differences in NH_3-N concentrations were observed in only one district, LNID, where greater concentrations were found in source water compared to return flow. However, the high pH and temperatures found in the irrigation network mean that small increases in NH_3-N could impact aquatic life.

Salinity and Major Ions. The EC guideline for irrigation was met in all but five samples. Samples that did not meet the guidelines were from source and return flow water in the WID. Five districts (LNID, MID, RID, SMRID, and UID) had significantly greater EC concentrations in return flow compared with source water. The BRID had significantly greater EC in source water than all the other districts. The EC remained low throughout the AID and MVID, while the greatest increases in EC were in MID and WID.

Total dissolved solids are related to EC; therefore, similar patterns were observed. The lower threshold TDS guideline for irrigation was exceeded in 2.5% of samples (16/631) and the exceedences included source water from the BRID and WID. Irrigation water in exceedence of the TDS guideline may impact crop productivity in sensitive fruit and bean crops, but can be tolerated by most cereals.

The SAR guideline for irrigation was met in all but four samples from the WID. All four of these samples also had EC in excess of 1000 $\mu S\ cm^{-1}$, but only one site was a source water site (the remaining three were return flow sites). Seven districts (EID, LNID, MID, SMRID, RID, TID, and UID) had significantly greater SAR values in return flow

compared with source water. The BRID and WID had significantly greater SAR in source water than the other districts.

Alberta waters tend to be naturally above the recommended optimal alkalinity concentrations of 30 to 60 mg L^{-1} for greenhouse plants. Alkalinity values, measured as $CaCO_3$, ranged from about 70 to 350 mg L^{-1}, with median site concentrations ranging from about 100 to 170 mg L^{-1}. These naturally high levels would be a concern for small container plants if the water was also high in pH. Further, high alkalinity can cause blockages in irrigation equipment from precipitation of Ca and Mg ions (and increase SAR). High alkalinity levels likely have negligible impacts on field crops.

All samples met the irrigation guideline for Cl^- and the livestock watering guideline for SO_4^{-2}. However, five irrigation districts (LNID, MID, RID, SMRID, and TID) had significantly greater Cl concentrations in return flow compared to source water. Seven districts (EID, LNID, MID, RID, SMRID, TID, and UID) had significantly greater SO_4^{-2} concentrations in return flow compared to source water. In several districts, the Cl^- and SO_4^{-2} concentrations were also significantly greater in secondary than primary source sites, which may be of concern if the trend continues in the future.

Metals. Samples were tested for a total of 25 metals. The most commonly detected metals were Ba, Fe, and U which were detected in 100% of the samples. Aluminum, As, and Mn were detected in more than 90% of the samples. Conversely, Ag, Mo, and Sn were not detected in any samples, while Be, Cd, and Co were detected in only single samples from the LNID. Chromium and Hg detections were rare, with Cr detected in only five samples and Hg detected in 14 samples out of a total of 615 samples.

Of the 17 metals discussed, five metals never exceeded guidelines (B, Li, Ni, U, and V) and three metals (Sb, Ba, and Ti) do not have guidelines. There were eight metals (Al, As, Cu, Fe, Pb, Se, Tl, and Zn) that exceeded water quality guidelines for the protection of aquatic life. Exeedances of the protection of aquatic life guidelines were most common for Al and As. Three metals exceeded irrigation guidelines and two exceeded livestock watering guidelines. Iron, Mn, Al, and As exceeded irrigation and/or livestock guidelines in less than 0.5% of samples. Most metals were detected more frequently in return flows for most districts, except the EID and the AID. The EID and AID tended to have greater concentrations of Al, Fe (AID only), Pb, and V in primary source water rather than return flow water. Primary site concentrations of these metals were also greater in the AID and EID compared to other districts. Although some of these metals are likely due to natural sources, they should be monitored.

Bacteria and Total Suspended Solids. The total coliform guideline for irrigation was met for about 44% of the samples. Six districts (BRID, EID, LNID, RID, TID, and UID) had significantly greater total coliform concentrations in return flow than primary source water. Most districts, except AID and TID, had significantly greater *E. coli* counts in return flow than primary source water. In two irrigation districts, the EID and UID, secondary source sites had significantly lower *E. coli* than primary sites, while the BRID and WID secondary sites had significantly greater *E. coli* concentrations than primary

sites. Many samples exceeded the limits of detection and therefore, some differences may have been missed.

Total suspended solid concentrations ranged from below detection at several sites to 164 mg L^{-1}. Five districts (LNID, MID, RID, TID, and UID) had significantly greater concentrations of TSS in return flow compared to source water. In contrast, two districts (AID and EID) had significantly greater TSS concentrations in primary source water than return flows. The greatest changes in TSS concentrations were observed among sites in the LNID.

The CCME guidelines for protection of aquatic life were exceeded in 7.7% of samples, with the greatest frequency of exceedance in the SMRID and TID.

Pesticides. Of the 25 pesticides (17 herbicides, 8 insecticides) analyzed, nine herbicides were detected. Pesticides were detected in more than 90% of the samples. The most commonly detected herbicides were: 2,4-D (91%), dicamba (47%), MCPA (38%), mecoprop (12%), and dichlorprop (10%). The remaining four compounds (bromoxynil, clopyralid, picloram, and triallate) were detected in less than 10% of samples.

Detection frequencies were similar to other Alberta studies and generally, those herbicides with the greatest sales and most mobility are the most commonly detected. Guidelines for 2,4-D were rarely exceeded; however, dicamba and MCPA irrigation guidelines were frequently exceeded. Dicamba exceeded irrigation guidelines every time it was detected and MCPA exceeded irrigation guidelines in 92% of the samples in which it was detected. Trillate, bromoxynil, and picloram were well below guidelines and no guidelines exist for clopyralid, dichlorprop, and mecoprop.

Pesticides were detected in 100% of the samples from SMRID. The BRID, EID, RID, TID, and LNID all had detection frequencies greater than 90%. The lowest detection frequencies were in the MID (48%), UID (62.5%) and MVID (62.5%). Detection frequencies were generally greater in the return flows, followed by the secondary and then primary source waters.

Four districts (BRID, LNID, TID, and UID) had significantly greater pesticide concentrations in return flows than source water. Total pesticide concentrations were significantly greater in source water of the WID than in all the other irrigation districts. Differences among the districts in return flow pesticide concentrations were less pronounced.

The majority of samples contained only one (33%) or two (31%) pesticide compounds. The maximum pesticide compounds per sample were eight. All samples that contained greater than six pesticide compounds were from the WID. In addition, the highest pesticide concentrations were observed in the WID. The greater compound pesticide detections and concentrations in the WID source water may, in part, be due to stormwater runoff from the City of Calgary and community of Chestermere.

Alberta Irrigation Water Quality Indices. Overall, irrigation water quality, as rated by the irrigation water quality index, was 'good' or 'excellent' for most of the source waters. Return flows generally had poorer water quality, but not in all cases. One site from each of the WID and EID rated 'marginal', while one site from each of these districts rated 'fair'.

Similarly, most sites rated either 'excellent' or 'good' for the protection of aquatic life index, with two sites rated as 'marginal', due to higher concentrations of metals.

Representative Sites

The representative sampling at the seven sites in the SMRID during 2006 and 2007 provided some information on the seasonality of parameters and comparisons of pipeline and earth canal infrastructure.

Infrastructure Comparison. Nutrient concentrations did not significantly vary between the pipeline and earth canal sites. The TP and TN values were generally below guidelines. There was a narrow range of DRP concentrations and NO_2-N was not detected at any of the sites.

Salinity and major ions did not significantly vary between pipeline and canal sites. The values of EC, TDS, SAR, alkalinity, Cl^-, and SO_4^{-2} tracked each other closely among sites.

Most metals did not vary between pipeline and canal sites, including As, Ba, B, Fe, Mn, Se, and U. As with the comprehensive sites, about 80% of the samples exceeded the Al guideline for the protection of aquatic life. Lead was detected in more than half of the samples, including all of the return flow (SMC-R4) samples. Titanium was detected in a greater proportion of representative samples (95%) than comprehensive samples (84%).

A few metal parameters showed some differences among sites. Interestingly, the Al and Pb concentrations were significantly greater at the source water site (SMC-S3) than near the end of the pipeline. Aluminum and V concentrations were also significantly greater at the source water site than at the end of the earth canal. There was an outlier in the Fe concentrations, which may have been due to an internal source; however, there were no significant differences in the concentrations.

Bacteria concentrations were significantly different among sites. Higher total coliform concentrations were observed at the return flow site (SMC-R4) and toward the end of the earth canal (SMC-E2 and SMC-E3) than the other sites. The *E. coli* concentrations followed a similar pattern.

There were no significant differences among the seven representative sites for any individual pesticide or total pesticide concentration. The maximum number of pesticide compounds detected in a sample from representative sites was six, which was detected at the three earth canal sites in June 2006. About 80% of samples had between one and three compounds per sample.

Most water quality index scores for the representative sites were 'good' except for the source water site, which scored as 'fair'. This index was primarily driven by pesticide concentrations, rather than significant differences among sites.

In conclusion, the findings did not conclusively support pipelines for water quality preservation. Certainly, it appears that bacteria were significantly reduced by the implementation of pipelines, but most other variables were unchanged.

Seasonality. Nutrient concentrations were generally greater in May, although some peaks occurred at different sites at other times of the year. Nutrient concentrations were generally greater in 2006 than in 2007. Ammonia detections only occurred in either May or October, when flows were reduced. In contrast, maximum NO_3-N concentrations were detected in July 2006.

Salinity and major ion concentrations also tended to peak at the beginning of the irrigation season, including EC and TDS concentrations. The SAR values also peaked in May and then declined towards a steady level, followed by a slight increase in October. Alkalinity had greater seasonal variation than the other parameters, particularly in 2007. Chloride and SO_4^{-2} concentrations peaked in May or June and then decreased throughout the irrigation season.

Metal concentrations also tended to peak in May. Similar to SAR, U tended to peak in the spring, decline, and then peak again at the end of the irrigation season. Greater concentrations of Sb, and Zn were generally observed in 2006 than 2007. Barium, B, Ti, and V concentrations were elevated in June and July in 2006. Arsenic was rarely detected in 2007, while B was not detected at all in 2007. Conversely, Ni had a greater number of detections in 2007 than in 2006. Concentrations of Cu remained similar until a peak in September 2007. Iron, Li, and Se did not show a seasonal pattern.

The *E. coli* concentrations at the end of the earth canal (SMC-E3) were greater in 2006 than in 2007, with peaks in June and September in both years. The concentrations at the return site peaked in July 2006.

Maximum pesticide concentrations were observed in either June or July for both years of the study.

It may be assumed that the representative study generally reflected the seasonality patterns for parameters throughout the districts. While there was a lot of variation in individual parameters, seasonal differences were generally minor. The concentrations of most parameters peaked at the beginning or near the end of the irrigation season when lower flows were common. Annual variation was also evident, which was likely influenced by weather.

RECOMMENDATIONS

This study was the first study to comprehensively evaluate the water quality in Alberta's 13 irrigation districts. The baseline information that the study provides may be used by the irrigation districts, irrigation producers, and water users within the districts. Water quality will continue to be a focus for the limited water supply in Alberta and hence, there are several recommendations for future studies.

- Future studies may provide additional information on the ability of pipelines to preserve water quality. Further studies should consider including several pipelines and earth canals. Studies should endeavour to characterize longer water flow paths through the irrigation water conveyance system.

- Further work should be done to ensure the sites that were chosen to evaluate the districts adequately represent water quality in each of the districts. In some cases, it may be prudent to increase the number of sites that are sampled to characterize source or return flow. It may also be beneficial to sample sites more frequently or with a different sampling regime (e.g., flow-biased with automated samplers). For instance, the majority of sites in the current study were sampled during prolonged dry periods when canals were full and irrigation was occurring. However, characterization of return flow contributions is best done during the spring and periods of rainfall, to ensure that transport mechanisms are captured. The addition of sites for water quality evaluation would have to be assessed in combination with sampling logistics and costs.

- Now that a baseline has been provided on a wide range of variables, future investigations should attempt to evaluate particular variables of interest. Further, future studies should consider more sensitive detection limits and increasing upper threshold limits for bacteria enumeration. For example, more than half of the samples in this study exceeded the upper threshold for bacteria, and this made it difficult to enumerate concentrations and conduct statistical analyses.

- While most of the return flows that were investigated in the current study were not monitored for flow, flow volumes would be beneficial to assess the impact on receiving bodies downstream.

- Efforts should be made towards gathering comprehensive, comparable irrigation water quality data into a long-term database for Alberta. This information will be critical for documenting the quality of water that is used in food production as well as maintaining rural communities, recreation, or wetland habitat. The information will also be valuable to assess long-term water quality trends. Data may also be used to assess the mitigation practices that are undertaken to protect water quality, either from communities upstream of the source water or within the irrigation districts. The current study provides a framework for this database and future efforts should strive to contribute in a coordinated and consolidated manner.

• Linkages between land use in the irrigation districts and water quality need to be made. Of particular interest would be to document point sources, particularly during spring runoff or rain events. For example, it would be worthwhile to document the location of road borrow pits that empty into return flow or earth canals and possibly sample upstream and downstream of these point sources. Additionally, topography and runoff modelling may assist in assessing if canal banks are sufficient to divert runoff.

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TABLES

Table 1. Irrigation districts, abbreviations, and locations of the comprehensive study sites.

Irrigation District	Primary			Secondary			Return Flow		
	Site	Lat. (°N)	Long. (°W)	Site	Lat. (°N)	Long. (°W)	Site	Lat. (°N)	Long. (°W)
Aetna	A-P1	49.16	113.40				A-R1	49.13	113.27
Bow River	AEP-P3	50.82	113.43	AEP-S3	50.27	112.82	BR-R1	50.42	112.34
	BR-P1	50.21	112.67	BR-S1	50.38	112.44	BR-R2	50.22	112.09
				BR-S2	50.13	112.30	BR-R3	49.97	112.08
				BR-S3	50.13	112.25	BR-R4	49.92	111.75
				BR-S4	50.12	112.03	BR-R5	50.04	111.58
				BR-S5	50.06	111.80	BR-R6	50.42	112.34
Eastern	E-P1	50.75	112.47	E-S1	50.86	112.36	E-R1	51.10	112.11
				E-S2	50.70	112.15	E-R2	50.83	111.68
				E-S3	50.43	112.09	E-R3	50.22	111.96
				E-S4	50.49	111.90	E-R4	50.71	111.60
				E-S5	50.37	111.88	E-R5	50.15	111.69
				E-S6	50.53	111.66			
Leavitt	A-P1	49.16	113.40						
Lethbridge Northern	LN-P1	49.73	113.55	LN-S1	49.91	113.18	LN-R1	50.03	112.73
				LN-S2	49.95	112.95	LN-R2	49.87	112.60
				LN-S3	49.79	112.93			
				LN-S4	49.92	112.80			
				LN-S5	49.89	112.77			
Magrath	M-P1	49.35	113.06	AEP-S1	49.33	113.57	M-R1	49.49	112.93
	M-P2	49.38	112.90	AEP-S2	49.38	113.22			
	AEP-P1	49.33	113.63						
Mountain View	MV-P1	49.11	113.63				MV-R1	49.18	113.64
Raymond	R-P1	49.42	112.68				R-R1	49.53	112.51
							R-R2	49.55	112.77
St. Mary	SMW-P1	49.58	112.71	SMW-S1	49.63	112.70	SMW-R1	49.72	112.49
	SMC-P1	49.71	112.00	SMC-S1	49.76	111.73	SMW-R2	49.84	112.43
	SME-P1	49.99	110.99	SMC-S2	49.80	111.67	SMC-R1	49.89	111.68
				SMCS3	49.70	111.43	SMC-R2	49.79	111.54
				SME-S1	49.82	110.93	SMC-R3	49.90	111.52
							SMC-R4	49.87	111.45
							SME-R1	49.94	110.63
Taber	T-P1	49.74	112.46	T-S1	49.74	112.24	T-R1	49.89	112.07
				T-S2	49.81	112.10	T-R2	49.90	111.86
				T-S3	49.83	111.97			
United	U-P1	49.21	113.64	U-S1	49.33	113.61	U-R1	49.44	113.34
							U-R2	49.45	113.39
Western	AEP-P2	51.01	113.85	W-S1	51.07	113.41	W-R1	not sampled	
	W-P1	50.91	113.61	W-S2	50.92	113.04	W-R2	50.83	112.76
	W-P2	51.07	113.80	W-S3	51.10	113.28			
				W-S4	51.22	113.33			

Table 2. Receiving bodies for return flows.

Irrigation District	Return Flow	Receiving Body
Aetna	A-R1	Aetna Creek
Bow River	BR-R1	Bow River
	BR-R2	Bow River
	BR-R3	Oldman River
	BR-R4	Oldman River
	BR-R5	Bow River
Eastern	E-R1	Red Deer River
	E-R2	Red Deer River
	E-R3	Bow River
	E-R4	Red Deer River
	E-R5	Bow River
Lethbridge Northern	LN-R1	Little Bow River
	LN-R2	Oldman River
Magrath	M-R1	St. Mary River
Mountain View	MV-R1	Belly River
Raymond	R-R1	Etzikom Coulee
	R-R2	Pothole Creek
St. Mary	SMW-R1	Stafford Lake
	SMW-R2	Oldman River
	SMC-R1	South Saskatchewan River
	SMC-R2	Yellow Lake
	SMC-R3	South Saskatchewan River
	SMC-R4	South Saskatchewan River
	SME-R1	Bullshead Creek
Taber	T-R1	Oldman River
	T-R2	Oldman River
United	U-R1	Belly River
	U-R2	Waterton River
Western	W-R2	Bow River

Table 3. A summary of nutrient, physical, and microbiological variables, methods, detection limits (D.L.), and guideline (G.L.) types and values.

Variable	Abbr	Unit	Method	D.L.	G.L. type*	G.L.
			Nutrients			
Ammonia-N	NH_3-N	mg L^{-1}	APHA 4500-NH3 G. Automated Phenate	0.05		
Nitrate-N	NO_3-N	mg L^{-1}	APHA 4110 B. Ion Chromatography	0.05		
Nitrite-N	NO_2-N	mg L^{-1}	APHA 4110 B. Ion Chromatography	0.05	PAL	0.06
					Livestock	10
Total Kjeldahl Nitrogen	TKN	mg L^{-1}	APHA 4500N_{org} C. Semi Micro- Kjeldahl	0.2		
Total Nitrogen	TN	mg L^{-1}	Calculated		PAL	1.0
Dissolved Reactive Phosphorus	DRP	mg L^{-1}	APHA 4500-P E. Ascorbic Acid	0.01		
Total Phosphorus	TP	mg L^{-1}	APHA 4500-P B.5 Persulfate Digestion. APHA 4500-P E. Ascorbic Acid	0.02	PAL	0.05
			Ions			
Alkalinity, Total (as $CaCO_3$)	Alk	mg L^{-1}	APHA 2320 B. Titration	5		
Bicarbonate	HCO_3	mg L^{-1}	APHA 2320 B. Titration	5		
Calcium, Dissolved	Ca	mg L^{-1}	APHA 3120 B. ICP (OES)	0.5	Livestock	1000
Calcium, Total	TotCa	mg L^{-1}	EPA 3015 Microwave Digestion EPA 200.7 ICP	0.5		
Carbonate	CO_3	mg L^{-1}	APHA 2320 B. Titration	5		
Chloride	Cl	mg L^{-1}	APHA 4110 B. Ion Chromatography	0.1	Irrigation	100 – 700
Conductivity	EC	µS cm^{-1}	APHA 2320 B. Titration	0.3	Irrigation	1000
Hardness (as $CaCO_3$)	Hard	mg L^{-1}	APHA 4110 B. Ion Chromatography			
Hydroxide	OH	mg L^{-1}	APHA 2320 B. Titration	5		
Ion Balance	Ion	%	Calculated			
Magnesium, Dissolved	Mg	mg L^{-1}	APHA 3120 B. ICP (OES)	0.1		
Magnesium, Total	TotMg	mg L^{-1}	EPA 3015 Microwave Digestion EPA 200.7 ICP	0.1		
pH	pH	mg L^{-1}	APHA 4500-H^+ B. Electrometric	0.1	PAL	<6.5 >9.0
Potassium, Dissolved	K	mg L^{-1}	APHA 3120 B. ICP (OES)	0.1		
Potassium, Total	TotK	mg L^{-1}	EPA 3015 Microwave Digestion EPA 200.7 ICP (OES)	0.1		
Sodium	Na	mg L^{-1}	APHA 3120 B. ICP (OES)	1		
Sodium, Total	TotNa	mg L^{-1}	EPA 3015 Microwave Digestion EPA 200.7 ICP	1		
Sodium Adsorption Ratio	SAR		Calculated		Irrigation	5.0
Sulphate	SO_4^{-2}	mg L^{-1}	APHA 4110 B. Ion Chromatography	0.5	Livestock	1000
Total Dissolved Solids	TDS	mg L^{-1}	APHA 1030 F.		Irrigation	500 - 3500
			Physical and Microbiological			
Total coliforms	TotColi	MPN 100mL^{-1}	APHA 9223 B. Chromogenic Substrate Test		Irrigation	1000
E. coli	Ecoli	MPN 100mL^{-1}	APHA 9223 B. Chromogenic Substrate Test		Irrigation Recreation	100** 200
Temperature	Temp	°C	*In situ* reading			
Total suspended solids	TSS	mg L^{-1}	APHA 2540 D. Total Suspended Solids Dried at 103-105°C	3	PAL	

*PAL = Protection of aquatic life; **Irrigation guideline is for fecal coliforms.

Table 4. A summary of total metal variables, methods, detection limits (D.L.), and guideline (G.L.) types and values ($mg\ L^{-1}$).

Variable	Abbr.	Method	D.L.	G.L. type*	G.L.
Aluminum	Al	EPA 3015 Microwave Assisted Digestion	0.01	PAL	0.1
		EPA 6020 ICP Method (MS)		IRR/LS	5
Antimony	Sb	EPA 3015 Microwave Assisted Digestion	0.0004		
		EPA 6020 ICP Method (MS)			
Arsenic	As	EPA 3015 Microwave Assisted Digestion	0.0004	PAL	0.005
		EPA 6020 ICP Method (MS)		LS	0.025
				IRR	0.100
Barium	Ba	EPA 3015 Microwave Assisted Digestion	0.003		
		EPA 6020 ICP Method (MS)			
Beryllium	Be	EPA 3015 Microwave Assisted Digestion	0.001	IRR/LS	0.100
		EPA 6020 ICP Method (MS)			
Boron	B	EPA 3015 Microwave Assisted Digestion	0.05	IRR	0.50-6.0
		EPA 6020 ICP Method (MS)		LS	5.0
Cadmium	Cd	EPA 3015 Microwave Assisted Digestion	0.0002	PAL	0.000005–0.000097[H]
		EPA 6020 ICP Method (MS)			0.0051
				IRR	0.080
				LS	
Chromium	Cr	EPA 3015 Microwave Assisted Digestion	0.005	IRR	0.0049
		EPA 6020 ICP Method (MS)		LS	0.05
Cobalt	Co	EPA 3015 Microwave Assisted Digestion	0.002	IRR	0.050
		EPA 6020 ICP Method (MS)		LS	1.0
Copper	Cu	EPA 3015 Microwave Assisted Digestion	0.001	PAL	0.002 – 0.004[H]
		EPA 6020 ICP Method (MS)		IRR	0.2 to 1.0
				LS	0.5-5.0
Iron	Fe	EPA 3015 Microwave Assisted Digestion	0.005	PAL	0.3
		EPA 6020 ICP Method (MS)		IRR	5.0
Lead	Pb	EPA 3015 Microwave Assisted Digestion	0.0001	PAL	0.001 – 0.007[H]
		EPA 6020 ICP Method (MS)		LS	0.100
				IRR	0.200
Lithium	Li	EPA 3015 Microwave Assisted Digestion	0.01	IRR	2.5
		EPA 6020 ICP Method (MS)			
Manganese	Mn	EPA 3015 Microwave Assisted Digestion	0.001	IRR	0.2
		EPA 6020 ICP Method (MS)			
Mercury	Hg	EPA 3015 Microwave Assisted Digestion	0.0002	PAL	0.000026
		EPA 6020 ICP Method (MS)		LS	0.003
Molybdenum	Mo	EPA 3015 Microwave Assisted Digestion	0.005	IRR	0.010
		EPA 6020 ICP Method (MS)		LS	0.50
				PAL	0.073
Nickel	Ni	EPA 3015 Microwave Assisted Digestion	0.002	PAL	0.025-0.150[H]
		EPA 6020 ICP Method (MS)		IRR	0.200
Selenium	Se	EPA 3015 Microwave Assisted Digestion	0.0004	PAL	0.001
		EPA 6020 ICP Method (MS)		IRR	0.020-0.050
Silver	Ag	EPA 3015 Microwave Assisted Digestion	0.0004	PAL	0.0001
		EPA 6020 ICP Method (MS)			
Thallium	Tl	EPA 3015 Microwave Assisted Digestion	0.0001	PAL	0.0008
		EPA 6020 ICP Method (MS)			
Tin	Sn	SW-846-6020 –ICPMS	0.050		
Titanium	Ti	EPA 3015 Microwave Assisted Digestion	0.001		
		EPA 6020 ICP Method (MS)			
Uranium	U	EPA 3015 Microwave Assisted Digestion	0.0001	IRR	0.010
		EPA 6020 ICP Method (MS)			
Vanadium	V	EPA 3015 Microwave Assisted Digestion	0.001	IRR	0.100
		EPA 6020 ICP Method (MS)			
Zinc	Zn	EPA 3015 Microwave Assisted Digestion	0.004	PAL	0.030
		EPA 6020 ICP Method (MS)		IRR	5.0

*PAL = Protection of Aquatic Life, IRR = Irrigation, LS = Livestock. [H] indicates guidelines are hardness dependent.

Table 5. A summary of pesticide variables, pesticide type, and guidelines.

Pesticides*	Abbr.	Pesticide Type	Units	Guideline Type**	Guideline
2,4-D	2,4-D	Herbicide	$\mu g\ L^{-1}$	PAL	4
2,4-D, B	2,4-DB	Herbicide	$\mu g\ L^{-1}$		
Atrazine	ATRA	Herbicide	$\mu g\ L^{-1}$	PAL	1.8
				Irrigation	10
				Livestock	5
Bromacil	BROM	Herbicide	$\mu g\ L^{-1}$	Irrigation	0.2
				PAL	5
				Livestock	1100
Bromoxynil	BROX	Herbicide	$\mu g\ L^{-1}$	Irrigation	0.33
				PAL	5
				Livestock	11
Chlorpyrifos	CHPY	Herbicide	$\mu g\ L^{-1}$	PAL	0.0035
				Livestock	24
Clopyralid	CLOP	Herbicide	$\mu g\ L^{-1}$		
Dicamba	DICM	Herbicide	$\mu g\ L^{-1}$	Irrigation	0.006
				PAL	10
				Livestock	122
Dichlorprop	DCPR	Herbicide	$\mu g\ L^{-1}$		
Diclofop-methyl	DICF	Herbicide	$\mu g\ L^{-1}$	Irrigation	0.18
				PAL	6
				Livestock	9
Ethalfluralin	ETFL	Herbicide	$\mu g\ L^{-1}$		
Fenoxaprop	FENO	Herbicide	$\mu g\ L^{-1}$		
Imazethapyr	IMAZ	Herbicide	$\mu g\ L^{-1}$		
MCPA	MCPA	Herbicide	$\mu g\ L^{-1}$	Irrigation	0.025
				PAL	2.6
				Livestock	25
Mecoprop	MECO	Herbicide	$\mu g\ L^{-1}$		
Picloram	PICL	Herbicide	$\mu g\ L^{-1}$	PAL	29
				Livestock	190
Quinclorac	QUIN	Herbicide	$\mu g\ L^{-1}$		
Triallate	TRAL	Herbicide	$\mu g\ L^{-1}$	PAL	0.24
				Livestock	230
Trifluralin	TRFL	Herbicide	$\mu g\ L^{-1}$	PAL	0.20
				Livestock	45
Aldrin	ALDR	Insecticide	$\mu g\ L^{-1}$		
DDE	DDE	Insecticide	$\mu g\ L^{-1}$		
Dieldrin	DIEL	Insecticide	$\mu g\ L^{-1}$		
Dimethoate	DIME	Insecticide	$\mu g\ L^{-1}$	Livestock	3
				PAL	6.2
Heptachlor	HEPT	Insecticide	$\mu g\ L^{-1}$	Livestock	3
Heptachlor-Epoxide	HEPE	Insecticide	$\mu g\ L^{-1}$		
Lindane	LIND	Insecticide	$\mu g\ L^{-1}$	Livestock	4
Methoxychlor	METC	Insecticide	$\mu g\ L^{-1}$		

*Detection limit for all pesticides is 0.025 $\mu g\ L^{-1}$. **PAL = Protection of aquatic life.

Table 6. Variables and objectives used in the Alberta Irrigation Water Quality Indices for Irrigation and Protection of Aquatic Life.

Irrigation		Protection of Aquatic Life	
Variable	**Objective***	**Variable**	**Objective****
SAR	5	pH	6.5 – 9.0
Cl	100 mg L^{-1}	TP	0.05 mg L^{-1}
TDS	500 mg L^{-1}	TN	1.0 mg L^{-1}
As	0.1 mg L^{-1}	NH_3-N	Calculated
Be	0.1 mg L^{-1}	NO_2-N	0.06 mg L^{-1}
B	0.5 mg L^{-1}	Al	0.1 mg L^{-1}
Cd	5.1 µg L^{-1}	As	0.005 mg L^{-1}
Cr	4.9 µg L^{-1}	Cu	0.002 – 0.004[11] mg L^{-1}
Cu	0.2 mg L^{-1}	Fe	0.3 mg L^{-1}
Fe	5.0 mg L^{-1}	Pb	0.001 – 0.007[11] mg L^{-1}
Pb	0.2 mg L^{-1}	Se	0.001 mg L^{-1}
Li	2.5 mg L^{-1}	Zn	0.03 mg L^{-1}
Mn	0.2 mg L^{-1}	*E. coli*	200 MPN 100 mL^{-1}
Se	0.02 mg L^{-1}	Bromoxynil	5 µg L^{-1}
U	0.01 mg L^{-1}	Picloram	29 µg L^{-1}
V	0.1 mg L^{-1}	Triallate	0.24 µg L^{-1}
Zn	5.0 mg L^{-1}	2,4-D	4 µg L^{-1}
*E. coli***	100 MPN 100 mL^{-1}		
Total Coliforms	1000 MPN 100 mL^{-1}		
Dicamba	0.006 µg L^{-1}		
MCPA	0.025 µg L^{-1}		
Bromoxynil	0.33 µg L^{-1}		
Diclofop-methyl	0.18 µg L^{-1}		

*The SAR objective is from Buckland et al. (2002); all others are CCME irrigation guidelines (CCREM 1987, CCME 1999)

**Total N (TN) and TP are Alberta Environment (1999) protection of aquatic life guidelines; *E. coli* is Alberta Environment (1999) recreation guideline; all other are CCME protection of aquatic life guidelines (CCREM 1987, CCME 1999).

***The methods for determining *E. coli* and total coliform concentrations are not specified (CCREM 1987); however, the values were reported as most probable number (MPN).

[11] Indicates objectives are hardness dependent.

Table 7. Mean nutrient concentrations (mg L^{-1}) in the primary, secondary, and return flow sites of the eleven irrigation districts from 2006 to 2007.

		AID	BRID	EID	LNID	MID	MVID	RID	SMRID	TID	UID	WID
TP	Primary	0.02	0.03	0.02	0.01	0.02	0.03	0.02	0.02	0.01	0.01	0.04
	Secondary		0.04	0.03	0.02	0.01			0.04	0.03	0.02	0.06
	Return	0.02	0.05	0.02	0.08	0.06	0.03	0.11	0.07	0.04	0.06	0.13
DRP	Primary	0.005	0.010	0.006	0.005	0.012	0.007	0.005	0.005	0.005	0.005	0.016
	Secondary		0.013	0.008	0.005	0.005			0.009	0.008	0.006	0.022
	Return	0.006	0.021	0.009	0.013	0.024	0.006	0.059	0.011	0.011	0.018	0.071
NO_3-N	Primary	0.03	0.29	0.37	0.07	0.07	0.03	0.13	0.04	0.02	0.05	0.05
	Secondary		0.02	0.09	0.03	0.04			0.03	0.02	0.03	0.14
	Return	0.03	0.04	0.03	0.02	0.17	0.03	0.03	0.03	0.02	0.03	0.14
NO_2-N	Primary	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Secondary		0.03	0.03	0.03	0.03			0.03	0.03	0.03	0.03
	Return	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
NH_3-N	Primary	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Secondary		0.03	0.03	0.03	0.03			0.03	0.03	0.03	0.03
	Return	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
TKN	Primary	0.34	0.32	0.49	0.10	0.17	0.50	0.14	0.33	0.16	0.10	0.39
	Secondary		0.72	0.44	0.32	0.10			0.50	0.56	0.19	0.49
	Return	0.31	0.65	0.36	0.56	0.34	0.51	0.38	0.84	0.61	0.32	0.66
TN	Primary	0.34	0.60	0.86	0.16	0.22	0.50	0.26	0.34	0.16	0.12	0.42
	Secondary		0.73	0.50	0.33	0.13			0.51	0.56	0.19	0.62
	Return	0.33	0.67	0.36	0.56	0.50	0.53	0.39	0.84	0.61	0.32	0.78
n	Primary	8	16	8	8	24	8	8	24	8	8	24
	Secondary	0	48	48	40	16	0	0	39	24	8	32
	Return	8	44	40	16	8	8	16	55	16	16	8

n = number of samples

Table 8. Mixed model degrees of freedom, F-values, and significance for total phosphorus.

	Degrees of Freedom (numerator, denominator*)	F-Value	P
	By Irrigation District		
AID	1, 14	0.77	0.394
BRID	2, 89	2.76	0.069
EID	2, 94	0.25	0.776
LNID	2, 61	45.0	0.001
MID	1, 22	3.52	0.074
MVID	1, 14	0.19	0.667
RID	1, 22	17.3	0.0004
SMRID	2, 115	5.67	0.004
TID	2, 45	4.73	0.014
UID	2, 29	26.6	0.0001
WID	2, 53	2.91	0.063
	By Site Type		
Primary	10,109	1.31	0.234
Secondary	6, 224	2.56	0.021
Return Flows	10, 224	5.54	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 9. Mixed model degrees of freedom, F-values, and significance for total dissolved phosphorus.

	Degrees of Freedom (numerator, denominator*)	F-Value	P
	By Irrigation District		
AID	1, 14	1.00	0.334
BRID	2, 89	1.95	0.148
EID	2, 94	0.38	0.684
LNID	2, 61	11.7	<0.0001
MID	1, 22	2.47	0.130
MVID	1, 14	1.27	0.278
RID	1, 22	8.20	0.009
SMRID	2, 115	1.84	0.163
TID	2, 45	1.82	0.173
UID	2, 29	18.9	<0.0001
WID	2, 53	3.07	0.055
	By Site Type		
Primary	10, 109	0.93	0.511
Secondary	6, 224	1.83	0.094
Return Flows	10, 224	13.1	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 10. Mixed model degrees of freedom, F-values, and significance for ammonia-nitrogen.

	Degrees of Freedom (numerator, denominator)*	F-Value	p
	By Irrigation District		
AID	1, 14	0.00	1.00
BRID	2, 89	0.45	0.642
EID	2, 93	0.58	0.564
LNID	2, 61	3.81	0.028
MID	1, 22	0.00	1.00
MVID	1, 14	0.00	1.00
RID	1, 22	0.49	0.492
SMRID	2, 115	1.22	0.299
TID	2, 45	0.45	0.640
UID	2, 29	1.55	0.229
WID	2, 53	0.32	0.728
	By Site Type		
Primary	10, 109	1.03	0.422
Secondary	6, 224	1.19	0.313
Return Flows	10, 224	0.28	0.985

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 11. Mixed model degrees of freedom, F-values, and significance for nitrate-nitrogen.

	Degrees of Freedom (numerator, denominator)*	F-Value	p
	By Irrigation District		
AID	1, 14	1.00	0.334
BRID	2, 89	1.10	0.336
EID	2, 94	45.10	<0.0001
LNID	2, 61	14.00	<0.0001
MID	1, 22	3.89	0.061
MVID	1, 14	1.00	0.334
RID	1, 22	5.42	0.030
SMRID	2, 115	1.21	0.303
TID	Did not converge		
UID	2, 29	5.77	0.008
WID	2, 53	0.70	0.502
	By Site Type		
Primary	10, 109	18.42	<0.0001
Secondary	6, 224	2.65	0.017
Return Flows	10, 224	7.37	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 12. Mixed model degrees of freedom, F-values, and significance for nitrite-nitrogen.

	Degrees of Freedom (numerator, denominator)*	F-Value	p
	By Irrigation District		
AID	1, 14	1.00	0.334
BRID	2, 89	1.56	0.216
EID	2, 92	0.00	1.00
LNID	2, 61	3.81	0.028
MID	1, 22	0.00	1.00
MVID	1, 14	1.00	0.334
RID	1, 22	0.98	0.333
SMRID	2, 115	0.77	0.466
TID	2, 45	0.00	1.00
UID	2, 29	1.64	0.211
WID	2, 53	3.24	0.047
	By Site Type		
Primary	10, 109	1.05	0.411
Secondary	6, 224	1.61	0.146
Return Flows	10, 223	2.50	0.007

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 13. Mixed model degrees of freedom, F-values, and significance for total Kjeldahl nitrogen.

	Degrees of Freedom (numerator, denominator)*	F-Value	p
	By Irrigation District		
AID	1, 14	0.09	0.767
BRID	2, 89	2.95	0.057
EID	2, 93	0.24	0.787
LNID	2, 61	22.35	<0.0001
MID	1, 22	3.25	0.085
MVID	1, 14	0.02	0.902
RID	1, 22	16.02	0.0006
SMRID	2, 115	5.94	0.004
TID	2, 45	10.65	0.0002
UID	2, 29	19.09	<0.0001
WID	2, 53	1.35	0.269
	By Site Type		
Primary	10, 109	3.81	0.0002
Secondary	6, 224	6.35	<0.0001
Return Flows	10, 224	4.55	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 14. Mixed model degrees of freedom, F-values, and significance for total nitrogen.

	Degrees of Freedom (numerator, denominator)*	F-Value	p
	By Irrigation District		
AID	1, 14	0.00	0.999
BRID	2, 89	2.82	0.065
EID	2, 93	6.48	0.002
LNID	2, 61	17.67	<0.0001
MID	1, 22	4.71	0.041
MVID	1, 14	0.08	0.778
RID	1, 22	2.99	0.098
SMRID	2, 115	5.50	0.005
TID	2, 45	12.24	<0.0001
UID	2, 29	13.84	<0.0001
WID	2, 57	6.26	0.004
	By Site Type		
Primary	10, 109	5.28	<0.0001
Secondary	6, 224	5.15	<0.0001
Return Flows	10, 224	4.28	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 15. Means of salinity variables in the primary, secondary, and return flow sites in the eleven irrigation districts from 2006 to 2007.

		AID	BRID	EID	LNID	MID	MVID	RID	SMRID	TID	UID	WID
TDS	Primary	117	313	205	151	123	118	139	169	174	118	291
($mg\ L^{-1}$)	Secondary		382	209	165	111			194	214	113	312
	Return	123	415	218	189	309	150	207	212	252	128	473
EC	Primary	210	510	348	268	218	208	241	282	289	210	471
($\mu S\ cm^{-1}$)	Secondary		616	350	283	197			319	333	200	509
	Return	217	666	364	322	490	260	348	344	376	228	720
SAR	Primary	0.20	1.24	0.49	0.22	0.20	0.16	0.33	0.57	0.55	0.09	1.24
	Secondary		1.84	0.66	0.52	0.12			0.71	1.02	0.12	1.48
	Return	0.22	2.02	0.71	0.67	1.72	0.21	0.91	0.86	1.26	0.16	2.57
Hardness	Primary	105	188	155	131	106	110	114	129	136	107	172
($mg\ L^{-1}$)	Secondary		196	148	125	100			139	136	103	169
	Return	112	206	151	137	173	134	139	143	143	115	210
Cl	Primary	0.40	10.62	7.06	0.68	0.48	0.34	0.75	1.18	1.13	0.23	18.92
($mg\ L^{-1}$)	Secondary		13.11	8.75	1.10	0.29			1.88	2.41	0.24	20.48
	Return	0.49	14.62	8.34	1.54	1.35	0.60	1.60	2.32	3.18	0.33	23.03
SO_4^{-2}	Primary	4.94	104.14	45.84	17.00	11.82	4.75	19.24	36.14	35.40	5.94	90.85
($mg\ L^{-1}$)	Secondary		159.04	54.38	31.76	7.41			47.45	68.85	7.88	108.41
	Return	5.36	172.93	61.32	43.89	119.22	4.81	55.90	59.47	93.89	11.55	189.68
n	Primary	8	16	8	8	24	8	8	24	8	8	24
	Secondary	0	48	48	40	16	0	0	39	24	8	32
	Return	8	44	40	16	8	8	16	55	16	16	8

n = number of samples

Table 16. Mixed model degrees of freedom, F-values, and significance for electrical conductivity.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	1.63	0.223
BRID	2, 89	1.51	0.226
EID	2, 93	0.88	0.417
LNID	2, 61	15.53	<0.0001
MID	1, 22	51.25	<0.0001
MVID	1, 14	1.76	0.206
RID	1, 22	17.41	0.0004
SMRID	2, 115	5.90	0.004
TID	2, 45	1.52	0.230
UID	2, 29	5.94	0.007
WID	2, 53	1.99	0.146
	By Site Type		
Primary	10, 109	34.34	<0.0001
Secondary	6, 224	83.98	<0.0001
Return Flows	10, 224	51.03	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 17. Mixed model degrees of freedom, F-values, and significance for total dissolved solids.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.62	0.445
BRID	2, 89	1.10	0.339
EID	2, 93	1.10	0.338
LNID	2, 61	12.81	<0.0001
MID	1, 22	46.97	<0.0001
MVID	1, 14	0.95	0.346
RID	1, 22	15.21	0.0008
SMRID	2, 113	5.46	0.005
TID	2, 44	4.27	0.020
UID	2, 29	2.76	0.080
WID	2, 53	3.38	0.042
	By Site Type		
Primary	10, 108	43.50	<0.0001
Secondary	6, 224	94.00	<0.0001
Return Flows	10, 222	52.55	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 18. Mixed model degrees of freedom, F-values, and significance for sodium adsorption ratio.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.17	0.683
BRID	2, 89	1.53	0.223
EID	2, 93	6.03	0.003
LNID	2, 61	10.60	0.0001
MID	1, 22	46.81	<0.0001
MVID	1, 14	1.01	0.332
RID	1, 22	11.16	0.003
SMRID	2, 113	5.01	0.008
TID	2, 45	6.02	0.005
UID	2, 29	7.23	0.003
WID	2, 53	2.99	0.059
	By Site Type		
Primary	10, 108	28.67	<0.0001
Secondary	6, 224	64.72	<0.0001
Return Flows	10, 223	54.25	<0.0001

*numerator = (treatments – 1), denominator = (sample size – n treatments).

Table 19. Mixed model degrees of freedom, F-values and significance for alkalinity.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.81	0.383
BRID	2, 89	5.86	0.004
EID	2, 93	2.66	0.075
LNID	2, 61	1.28	0.286
MID	1, 22	23.28	<0.0001
MVID	1, 14	1.38	0.259
RID	1, 22	7.55	0.012
SMRID	2, 115	2.16	0.120
TID	2, 45	1.09	0.346
UID	2, 29	1.65	0.210
WID	2, 53	3.87	0.027
	By Site Type		
Primary	10, 109	5.61	<0.0001
Secondary	6, 224	7.59	<0.0001
Return Flows	10, 224	10.72	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 20. Mixed model degrees of freedom, F-values, and significance for chloride.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.34	0.569
BRID	2, 89	2.10	0.129
EID	2, 93	2.06	0.133
LNID	2, 61	14.09	<0.0001
MID	1, 22	19.78	0.0002
MVID	1, 14	2.34	0.148
RID	1, 22	7.58	0.012
SMRID	2, 115	7.57	0.0008
TID	2, 45	6.92	0.002
UID	2, 27	2.17	0.133
WID	2, 53	0.08	0.923
	By Site Type		
Primary	10, 107	91.51	<0.0001
Secondary	6, 224	231.12	<0.0001
Return Flows	10, 224	150.79	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 21. Mixed model degrees of freedom, F-values, and significance for sulphate.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.99	0.337
BRID	2, 89	1.02	0.3661
EID	2, 93	7.99	0.0006
LNID	2, 61	20.99	<0.0001
MID	1, 22	73.30	<0.0001
MVID	1, 14	0.06	0.805
RID	1, 22	19.38	0.0002
SMRID	2, 115	5.04	0.008
TID	2, 45	7.05	0.002
UID	2, 29	26.10	<0.0001
WID	2, 53	2.76	0.072
	By Site Type		
Primary	10, 109	96.44	<0.0001
Secondary	6, 224	105.27	<0.0001
Return Flows	10, 224	96.10	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 22. Mean concentrations of metals (mg L^{-1}) in primary, secondary, and return flow sites in the eleven irrigation districts from 2006 to 2007.

		AID	BRID	EID	LNID	MID	MVID	RID	SMRID	TID	UID	WID
Aluminum	Primary	0.854	0.037	0.628	0.280	0.196	0.075	0.191	0.232	0.124	0.079	0.190
	Secondary		0.113	0.089	0.392	0.191			0.303	0.119	0.085	0.408
	Return Flow	0.466	0.260	0.116	2.079	1.279	0.559	1.479	0.365	0.130	1.969	1.241
Arsenic	Primary	0.0014	0.0009	0.0007	0.0026	0.0007	0.0011	0.0007	0.0012	0.0008	0.0002	0.0012
	Secondary		0.0020	0.0013	0.0026	0.0014			0.0034	0.0020	0.0005	0.0013
	Return Flow	0.0014	0.0019	0.0015	0.0015	0.0006	0.0014	0.0016	0.0031	0.0016	0.0012	0.0026
Boron	Primary	0.056	0.054	0.041	0.061	0.063	0.054	0.065	0.045	0.041	0.045	0.039
	Secondary		0.065	0.040	0.062	0.073			0.043	0.044	0.058	0.038
	Return Flow	0.062	0.063	0.040	0.072	0.136	0.063	0.056	0.044	0.051	0.055	0.053
Copper	Primary	0.0011	0.0012	0.0016	0.0032	0.0046	0.0005	0.0009	0.0008	0.0009	0.0005	0.0012
	Secondary		0.0013	0.0012	0.0012	0.0007			0.0010	0.0009	0.0005	0.0018
	Return Flow	0.0009	0.0015	0.0009	0.0009	0.0017	0.0009	0.0024	0.0011	0.0009	0.0018	0.0034
Iron	Primary	0.593	0.220	0.498	0.178	0.161	0.111	0.152	0.194	0.091	0.058	0.158
	Secondary		0.108	0.080	0.302	0.131			0.260	0.088	0.063	0.341
	Return Flow	0.309	0.267	0.127	1.820	1.102	0.554	1.102	0.320	0.158	1.403	1.004
Lead	Primary	0.0003	0.0002	0.0004	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002
	Secondary		0.0001	0.0001	0.0002	0.0001			0.0002	0.0001	0.0001	0.0003
	Return Flow	0.0002	0.0002	0.0002	0.0010	0.0006	0.0003	0.0006	0.0002	0.0001	0.0008	0.0006
Lithium	Primary	0.005	0.016	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.007
	Secondary		0.018	0.006	0.007	0.005			0.007	0.007	0.005	0.007
	Return Flow	0.005	0.019	0.008	0.008	0.010	0.006	0.006	0.010	0.008	0.006	0.020
Manganese	Primary	0.024	0.011	0.018	0.005	0.006	0.063	0.009	0.023	0.011	0.002	0.018
	Secondary		0.017	0.026	0.019	0.005			0.035	0.023	0.017	0.021
	Return Flow	0.011	0.027	0.022	0.062	0.036	0.026	0.040	0.034	0.029	0.037	0.060
n*	Primary	8	16	8	8	24	8	8	24	8	8	24
	Secondary	0	48	48	40	16	0	0	39	24	8	32
	Return Flow	8	44	40	16	8	8	16	55	16	16	8

*Due to lab issues, sample sizes for boron, copper, lead, and lithium are as follows: AID: 7,0,7; BRID: 15, 42, 38; LNID: 7, 35, 14; MID: 22,15,7; MVID: 7,0,7; RID: 7,0,14; UID: 6, 6, 14.

Table 23. Mean concentrations of metals (mg L^{-1}) in primary, secondary, and return flow sites in the eleven irrigation districts from 2006 to 2007.

		AID	BRID	EID	LNID	MID	MVID	RID	SMRID	TID	UID	WID
Nickel	Primary	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Secondary		0.001	0.001	0.001	0.001			0.001	0.001	0.001	0.002
	Return Flow	0.001	0.002	0.001	0.003	0.002	0.001	0.002	0.001	0.001	0.002	0.004
Selenium	Primary	0.0004	0.0007	0.0007	0.0008	0.0005	0.0004	0.0007	0.0004	0.0005	0.0004	0.0010
	Secondary		0.0008	0.0006	0.0010	0.0003			0.0004	0.0006	0.0005	0.0009
	Return Flow	0.0004	0.0008	0.0005	0.0008	0.0017	0.0004	0.0015	0.0005	0.0006	0.0004	0.0009
Thallium	Primary	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	Secondary		0.0001	0.0001	0.0001	0.0001			0.0001	0.0001	0.0001	0.0001
	Return Flow	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003
Titanium	Primary	0.025	0.012	0.013	0.014	0.013	0.009	0.013	0.010	0.006	0.007	0.008
	Secondary		0.011	0.006	0.016	0.012			0.012	0.006	0.010	0.014
	Return Flow	0.018	0.014	0.007	0.059	0.033	0.019	0.039	0.013	0.006	0.043	0.030
Uranium	Primary	0.0004	0.0012	0.0007	0.0004	0.0004	0.0003	0.0005	0.0008	0.0008	0.0003	0.0014
	Secondary		0.0016	0.0007	0.0006	0.0003			0.0009	0.0009	0.0004	0.0015
	Return Flow	0.0004	0.0016	0.0008	0.0009	0.0020	0.0005	0.0010	0.0009	0.0012	0.0005	0.0022
Vanadium	Primary	0.0025	0.0012	0.0016	0.0009	0.0009	0.0005	0.0008	0.0009	0.0006	0.0005	0.0011
	Secondary		0.0011	0.0008	0.0016	0.0006			0.0013	0.0008	0.0005	0.0017
	Return Flow	0.0018	0.0013	0.0007	0.0058	0.0036	0.0018	0.0042	0.0016	0.0011	0.0051	0.0048
Zinc	Primary	0.011	0.010	0.014	0.008	0.014	0.011	0.008	0.008	0.006	0.008	0.010
	Secondary		0.007	0.007	0.010	0.009			0.009	0.009	0.011	0.015
	Return Flow	0.012	0.010	0.010	0.017	0.011	0.011	0.011	0.008	0.010	0.016	0.015
n*	Primary	8	16	8	8	24	8	8	24	8	8	24
	Secondary	0	48	48	40	16	0	0	39	24	8	32
	Return Flow	8	44	40	16	8	8	16	55	16	16	8

*Due to lab issues, sample sizes for nickel, selenium, thallium, titanium, vanadium and zinc are as follows: AID: 7,0,7; BRID: 15, 42, 38; LNID: 7, 35, 14; MID: 22,15,7; MVID: 7,0,7; RID: 7,0,14; UID: 6, 6, 14.

Table 24. Mixed model degrees of freedom, F-values, and significance for aluminum.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	5.17	0.039
BRID	2, 77	3.84	0.026
EID	2, 93	18.72	<0.0001
LNID	2, 54	13.73	<0.0001
MID	1, 19	6.20	0.022
MVID	1, 14	9.30	0.009
RID	1, 19	42.62	<0.0001
SMRID	2, 115	0.96	0.386
TID	2, 45	0.09	0.916
UID	2, 29	19.30	<0.0001
WID	2, 53	18.11	<0.0001
	By Site Type		
Primary	10, 104	8.72	<0.0001
Secondary	7, 236	9.58	<0.0001
Return Flows	10, 213	19.83	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 25. Mixed model degrees of freedom, F-values, and significance for arsenic.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.61	0.447
BRID	2, 77	2.17	0.121
EID	2, 93	2.96	0.057
LNID	2, 54	17.55	<0.0001
MID	1, 19	4.39	0.050
MVID	1, 14	4.43	0.054
RID	1, 19	28.39	<0.0001
SMRID	2, 115	0.71	0.494
TID	2, 45	12.65	<0.0001
UID	2, 29	45.25	<0.0001
WID	2, 53	4.91	0.011
	By Site Type		
Primary	10, 104	2.96	0.003
Secondary	6, 215	2.52	0.022
Return Flows	10, 213	0.57	0.834

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 26. Mixed model degrees of freedom, F-values, and significance for barium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.24	0.630
BRID	2, 77	1.03	0.361
EID	2, 93	0.12	0.889
LNID	2, 54	3.51	0.036
MID	1, 19	0.02	0.886
MVID	1, 14	0.00	0.949
RID	1, 19	0.21	0.648
SMRID	2, 115	1.46	0.237
TID	2, 45	7.52	0.002
UID	2, 29	0.88	0.426
WID	2, 53	5.98	0.004
	By Site Type		
Primary	10, 109	24.20	<0.0001
Secondary	6, 215	32.33	<0.0001
Return Flows	10, 223	26.66	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 27. Mixed model degrees of freedom, F-values, and significance for boron.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.04	0.837
BRID	2, 77	0.07	0.930
EID	2, 93	0.00	0.999
LNID	2, 54	0.12	0.885
MID	1, 19	1.77	0.199
MVID	1, 14	0.07	0.795
RID	1, 19	0.09	0.765
SMRID	2, 115	0.01	0.994
TID	2, 45	0.10	0.907
UID	2, 29	0.10	0.907
WID	2, 53	0.66	0.522
	By Site Type		
Primary	10, 104	0.48	0.901
Secondary	6, 215	1.86	0.089
Return Flows	10, 213	1.56	0.122

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 28. Mixed model degrees of freedom, F-values, and significance for copper.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.43	0.523
BRID	2, 77	0.26	0.775
EID	2, 93	0.33	0.722
LNID	2, 54	13.15	<0.0001
MID	1, 19	0.39	0.538
MVID	1, 14	4.20	0.060
RID	1, 19	14.58	0.001
SMRID	2, 115	2.35	0.100
TID	2, 45	0.05	0.953
UID	2, 29	9.38	0.0007
WID	2, 53	3.56	0.035
	By Site Type		
Primary	10, 104	0.77	0.661
Secondary	6, 215	1.09	0.370
Return Flows	10, 213	9.40	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 29. Mixed model degrees of freedom, F-values, and significance for iron.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	8.09	0.013
BRID	2, 77	4.81	0.011
EID	2, 93	14.87	<0.0001
LNID	2, 54	14.93	<0.0001
MID	1, 19	9.14	0.007
MVID	1, 14	17.43	0.0009
RID	1, 19	39.24	<0.0001
SMRID	2, 115	1.41	0.248
TID	2, 45	3.12	0.054
UID	2, 29	15.69	<0.0001
WID	2, 53	18.99	<0.0001
	By Site Type		
Primary	10, 104	7.12	<0.0001
Secondary	6, 215	9.22	<0.0001
Return Flows	10, 216	16.44	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 30. Mixed model degrees of freedom, F-values, and significance for lead.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	5.92	0.029
BRID	2, 77	3.07	0.052
EID	2, 93	4.84	0.010
LNID	2, 54	11.13	<0.0001
MID	1, 19	2.37	0.140
MVID	1, 14	9.22	0.009
RID	1, 19	26.97	<0.0001
SMRID	2, 115	1.55	0.218
TID	2, 45	6.46	0.0034
UID	2, 29	8.48	0.0013
WID	2, 53	8.93	0.0005
	By Site Type		
Primary	10, 104	3.26	0.001
Secondary	6, 215	8.07	<0.0001
Return Flows	10, 213	9.60	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 31. Mixed model degrees of freedom, F-values, and significance for lithium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	No convergence		
BRID	2, 77	1.41	0.249
EID	2, 93	2.31	0.104
LNID	2, 54	0.72	0.489
MID	1, 19	7.40	0.014
MVID	1, 14	1.00	0.334
RID	1, 19	1.73	0.204
SMRID	2, 115	10.24	<0.0001
TID	2, 45	1.12	0.334
UID	2, 29	1.04	0.368
WID	2, 53	11.57	<0.0001
	By Site Type		
Primary	10, 104	5.28	<0.0001
Secondary	6, 215	21.50	<0.0001
Return Flows	10, 213	13.42	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 32. Mixed model degrees of freedom, F-values, and significance for manganese.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	25.18	0.0002
BRID	2, 77	7.89	0.0007
EID	2, 93	0.50	0.607
LNID	2, 54	20.18	<0.0001
MID	1, 19	8.85	0.007
MVID	1, 14	3.96	0.066
RID	1, 19	20.60	0.0002
SMRID	2, 115	1.03	0.362
TID	2, 45	7.79	0.001
UID	2, 29	6.32	0.005
WID	2, 53	16.92	<0.0001
	By Site Type		
Primary	10, 109	10.21	<0.0001
Secondary	6, 224	2.42	0.028
Return Flows	10, 223	4.23	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 33. Mixed model degrees of freedom, F-values, and significance for nickel.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	No convergence		
BRID	2, 77	0.47	0.624
EID	2, 93	0.98	0.380
LNID	2, 54	6.42	0.003
MID	1, 19	3.54	0.075
MVID	1, 14	1.00	0.334
RID	1, 19	3.07	0.096
SMRID	2, 115	1.27	0.286
TID	2, 45	0.80	0.454
UID	2, 29	5.29	0.011
WID	2, 53	11.35	<0.0001
	By Site Type		
Primary	10, 104	0.40	0.945
Secondary	6, 215	2.36	0.031
Return Flows	10, 213	6.98	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 34. Mixed model degrees of freedom, F-values, and significance for selenium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.15	0.704
BRID	2, 77	1.03	0.362
EID	2, 93	0.91	0.405
LNID	2, 54	0.30	0.743
MID	1, 19	11.20	0.003
MVID	1, 14	0.24	0.632
RID	1, 19	0.88	0.360
SMRID	2, 115	0.05	0.949
TID	2, 45	0.26	0.768
UID	2, 29	0.84	0.441
WID	2, 53	0.71	0.497
	By Site Type		
Primary	10, 104	4.48	<0.0001
Secondary	6, 215	3.34	0.004
Return Flows	10, 213	5.73	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 35. Mixed model degrees of freedom, F-values, and significance for thallium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	1.00	0.334
BRID	2, 77	1.92	0.154
EID	2, 93	0.87	0.422
LNID	2, 54	0.24	0.790
MID	1, 19	0.32	0.576
MVID	No convergence		
RID	1, 19	0.89	0.357
SMRID	2, 115	2.34	0.101
TID	2, 45	2.12	0.132
UID	2, 29	0.60	0.556
WID	2, 53	4.40	0.017
	By Site Type		
Primary	10, 104	1.75	0.079
Secondary	6, 215	0.97	0.445
Return Flows	10, 217	3.86	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 36. Mixed model degrees of freedom, F-values, and significance for titanium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.63	0.440
BRID	2, 77	0.38	0.683
EID	2, 93	1.68	0.192
LNID	2, 54	12.17	<0.0001
MID	1, 19	2.79	0.111
MVID	1, 14	1.09	0.314
RID	1, 19	9.87	0.005
SMRID	2, 115	0.57	0.564
TID	2, 45	0.03	0.968
UID	2, 29	7.44	0.002
WID	2, 53	7.00	0.002
	By Site Type		
Primary	10, 104	1.47	0.161
Secondary	6, 215	3.04	0.007
Return Flows	10, 213	11.96	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 37. Mixed model degrees of freedom, F-values, and significance for uranium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.76	0.398
BRID	2, 89	0.21	0.807
EID	2, 93	6.29	0.003
LNID	2, 61	29.06	<0.0001
MID	1, 21	26.82	<0.0001
MVID	1, 14	2.81	0.116
RID	1, 22	18.36	0.0003
SMRID	2, 115	1.88	0.156
TID	2, 45	5.70	0.006
UID	2, 29	37.45	<0.0001
WID	2, 53	2.80	0.070
	By Site Type		
Primary	10, 109	28.37	<0.0001
Secondary	6, 224	61.25	<0.0001
Return Flows	10, 223	24.05	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 38. Mixed model degrees of freedom, F-values, and significance for vanadium.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	2.21	0.159
BRID	2, 77	1.15	0.322
EID	2, 93	3.10	0.038
LNID	2, 54	11.08	<0.0001
MID	1, 19	6.15	0.023
MVID	1, 14	5.53	0.034
RID	1, 19	43.05	<0.0001
SMRID	2, 115	2.49	0.087
TID	2, 45	2.89	0.066
UID	2, 29	12.23	0.0001
WID	2, 53	18.78	<0.0001
	By Site Type		
Primary	10, 104	2.96	0.003
Secondary	6, 215	3.02	0.007
Return Flows	10, 213	14.67	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 39. Mixed model degrees of freedom, F-values, and significance for zinc.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0	0.964
BRID	2, 77	3.49	0.035
EID	2, 93	3.12	0.049
LNID	2, 54	2.37	0.103
MID	1, 19	0.34	0.565
MVID	1, 14	0.04	0.835
RID	1, 19	1.26	0.276
SMRID	2, 115	0.18	0.837
TID	2, 45	0.49	0.619
UID	2, 29	3.17	0.057
WID	2, 53	0.20	0.823
	By Site Type		
Primary	10, 104	0.91	0.525
Secondary	6, 215	1.02	0.416
Return Flows	10, 213	2.23	0.018

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 40. Mean values of bacteria and physical variables for primary, secondary, and return flow sites in the eleven irrigation districts from 2006 to 2007.

	Site Type	AID	BRID	EID	LNID	MID	MVID	RID	SMRID	TID	UID	WID
Total coliforms	Primary	1402	992	823	449	1073	844	867	1045	1272	225	1662
(MPN 100 mL^{-1})	Secondary		1007	828	897	489			1155	1471	866	1503
	Return	1275	1936	1800	2116	1886	1703	2143	1660	2020	1770	1890
E. coli	Primary	112	80	40	42	78	2	17	16	199	52	33
(MPN 100 mL^{-1})	Secondary		20	17	42	26			24	131	4	212
	Return	102	188	177	407	285	192	436	200	51	152	203
TSS	Primary	11	3	5	5	2	3	5	6	2	2	9
(mg L^{-1})	Secondary		4	3	6	3			8	4	2	7
	Return	3	6	3	49	21	8	22	10	4	33	19
pH	Primary	8.36	8.35	8.19	8.06	8.19	8.44	8.16	8.36	8.23	8.15	8.34
	Secondary		8.56	8.28	8.31	8.20			8.40	8.72	8.35	8.33
	Return	8.14	8.27	8.15	8.14	8.21	8.30	8.09	8.65	8.69	8.48	8.21
n	Primary	8	16	8	8	24	8	8	24	8	8	24
	Secondary	0	48	48	40	16	0	0	39	24	8	32
	Return	8	44	40	16	8	8	16	55	16	16	8

n = number of samples

Table 41. Mixed model degrees of freedom, F-values, and significance for total coliforms.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.00	0.992
BRID	2, 89	15.56	<0.0001
EID	2, 93	16.21	<0.0001
LNID	2, 61	11.72	<0.0001
MID	1, 22	1.09	0.308
MVID	1, 14	2.80	0.116
RID	1, 22	6.92	0.015
SMRID	2, 115	1.87	0.159
TID	2, 45	2.55	0.089
UID	2, 29	14.73	<0.0001
WID	2, 53	0.34	0.713
	By Site Type		
Primary	10, 109	4.38	<0.0001
Secondary	6, 224	4.09	0.0006
Return Flows	10, 224	0.81	0.616

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 42. Mixed model degrees of freedom, F-values, and significance for *Escherichia coli*.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.36	0.558
BRID	2, 89	51.11	<0.0001
EID	2, 93	34.10	<0.0001
LNID	2, 61	26.44	<0.0001
MID	1, 22	4.46	0.046
MVID	1, 14	163.91	<0.0001
RID	1, 22	73.82	<0.0001
SMRID	2, 115	22.25	<0.0001
TID	2, 45	0.33	0.724
UID	2, 29	30.56	<0.0001
WID	2, 53	47.32	<0.0001
	By Site Type		
Primary	10, 109	5.95	<0.0001
Secondary	6, 224	25.24	<0.0001
Return Flows	10, 224	4.08	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 43. Mixed model degrees of freedom, F-values, and significance for total suspended solids.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	11.78	0.004
BRID	2, 89	1.96	0.147
EID	2, 93	3.25	0.043
LNID	2, 61	22.96	<0.0001
MID	1, 22	19.62	0.0002
MVID	1, 14	2.78	0.118
RID	1, 22	33.22	<0.0001
SMRID	2, 115	1.50	0.228
TID	2, 45	3.37	0.042
UID	2, 29	17.27	<0.0001
WID	2, 53	3.09	0.054
	By Site Type		
Primary	10, 109	4.72	<0.0001
Secondary	6, 224	5.96	<0.0001
Return Flows	10, 228	16.20	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 44. Mean concentrations of the seven most commonly detected pesticides (ug L^{-1}) in the primary, secondary, and return flow sites in the eleven irrigation districts from 2006 to 2007.

	Site Type	AID	BRID	EID	LNID	MID	MVID	RID	SMRID	TID	UID	WID
2,4-D	Primary	0.082	0.095	0.059	0.003	0.036	0.026	0.071	0.175	0.113	nd	0.511
	Secondary		0.149	0.057	0.063				0.167	0.260	0.067	1.416
	Return	0.102	0.229	0.077	0.091	0.039	0.032	0.181	0.888	0.380	0.159	0.351
Dicamba	Primary	0.030	0.003	0.046	nd	nd	0.004	0.006	0.019	0.015	nd	0.060
	Secondary		0.018	0.015	0.001				0.015	0.037	0.034	0.269
	Return	0.027	0.038	0.224	0.004	0.025	Nd	0.009	0.039	0.057	0.076	0.128
MCPA	Primary	nd	0.019	nd	nd	0.005	Nd	0.008	0.082	0.058	nd	0.033
	Secondary		0.031	0.004	0.003				0.078	0.079	nd	0.110
	Return	nd	0.029	0.005	0.004	0.030	Nd	0.008	0.125	0.077	nd	0.044
Mecoprop	Primary	nd	nd	0.015	0.001	nd	Nd	nd	nd	0.000	nd	0.211
	Secondary		0.001	0.007	nd				0.001	0.009	nd	0.119
	Return	nd	0.002	0.003	nd	nd	Nd	nd	nd	0.004	nd	0.032
Dichlorprop	Primary	nd	nd	nd	nd	nd	Nd	nd	0.006	0.007	nd	0.001
	Secondary		0.003	nd	nd				0.004	0.015	nd	0.004
	Return	nd	0.007	0.001	nd	0.004	Nd	0.002	0.005	0.013	nd	0.005
Bromoxynil	Primary	nd	nd	nd	nd	nd	Nd	nd	0.001	nd	nd	nd
	Secondary		nd	nd	nd				0.001	nd	nd	0.004
	Return	nd	0.011	0.001	0.002	0.009	Nd	nd	nd	nd	nd	0.023
Clopyralid	Primary	nd	nd	nd	nd	nd	Nd	nd	nd	nd	nd	nd
	Secondary		0.002	nd	nd				nd	0.001	nd	0.002
	Return	nd	0.003	nd	nd	nd	Nd	nd	nd	nd	nd	0.003
n	Primary	8	16	8	8	24	8	8	24	8	8	24
	Secondary	0	48	48	40	16	0	0	39	24	8	32
	Return	8	44	40	16	8	8	16	55	16	16	8

[a] Not detected

n = number of samples

Table 45. Mixed model degrees of freedom, F-values, and significance for total pesticide concentration.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.11	0.744
BRID	2, 89	4.03	0.021
EID	2, 93	5.82	0.004
LNID	2, 61	4.99	0.010
MID	1, 22	2.74	0.112
MVID	1, 13	0.94	0.350
RID	1, 22	3.09	0.092
SMRID	2, 113	0.97	0.383
TID	2, 45	3.60	0.036
UID	2, 29	6.83	0.004
WID	2, 53	0.63	0.539
	By Site Type		
Primary	10, 108	10.84	<0.0001
Secondary	6, 223	16.45	<0.0001
Return Flows	10, 223	2.50	0.0003

*numerator = (treatments – 1), denominator = (sample size – treatments).

Table 46. Mixed model degrees of freedom, F-values, and significance for 2,4-D concentration.

	Degrees of Freedom (numerator, denominator*)	F-Value	p
	By Irrigation District		
AID	1, 14	0.25	0.625
BRID	2, 89	3.83	0.026
EID	2, 93	0.59	0.559
LNID	2, 61	6.53	0.003
MID	1, 22	0.03	0.863
MVID	1, 14	0.19	0.670
RID	1, 22	3.49	0.075
SMRID	2, 114	0.45	0.638
TID	2, 45	5.00	0.011
UID	2, 29	5.01	0.014
WID	2, 57	1.27	0.289
	By Site Type		
Primary	10, 109	10.95	<0.0001
Secondary	6, 224	11.73	<0.0001
Return Flows	10, 223	5.71	<0.0001

*numerator = (treatments – 1), denominator = (sample size – treatments).

FIGURES

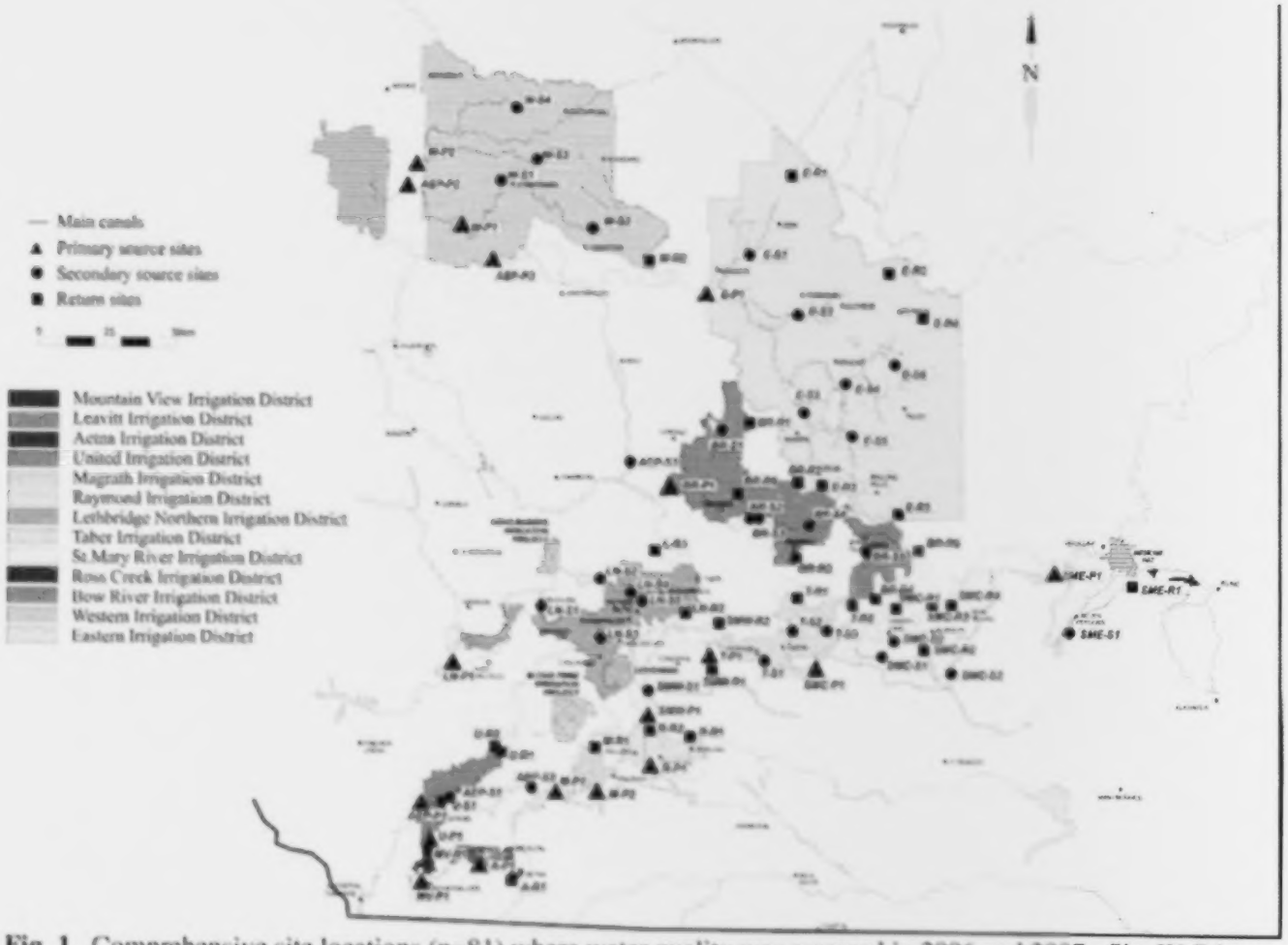

Fig. 1. Comprehensive site locations (n=81) where water quality was assessed in 2006 and 2007. Site W-R1 was removed from the dataset, and Site BR-R6 was added in 2007.

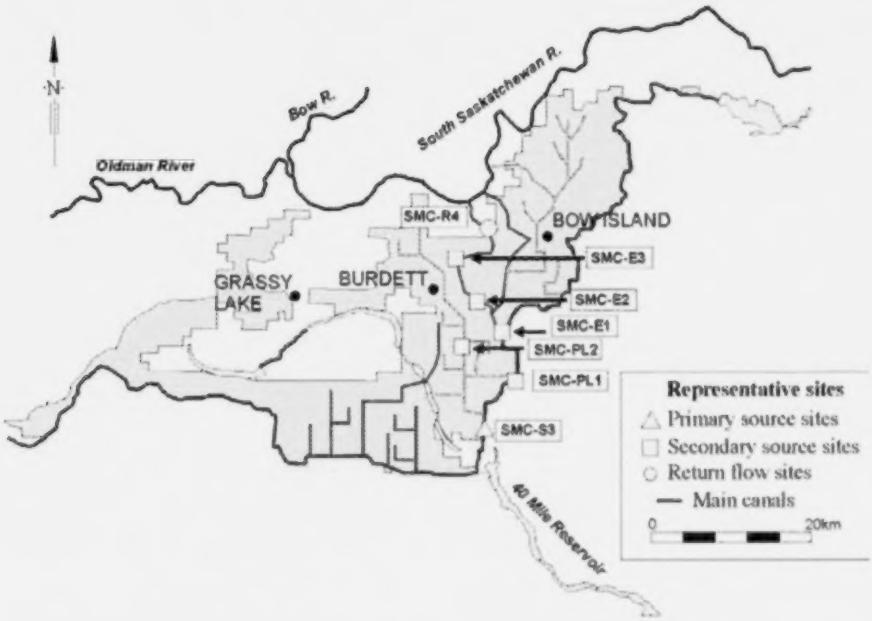

Fig. 2. Schematic of representative sites (n = 7) where water quality was assessed in 2006 and 2007 in the St. Mary River Irrigation District central. SMC-PL1 and SMC-PL2 are pipeline sites and SMC-E1, SMC-E2, and SMC-E3 are open earth canal sites

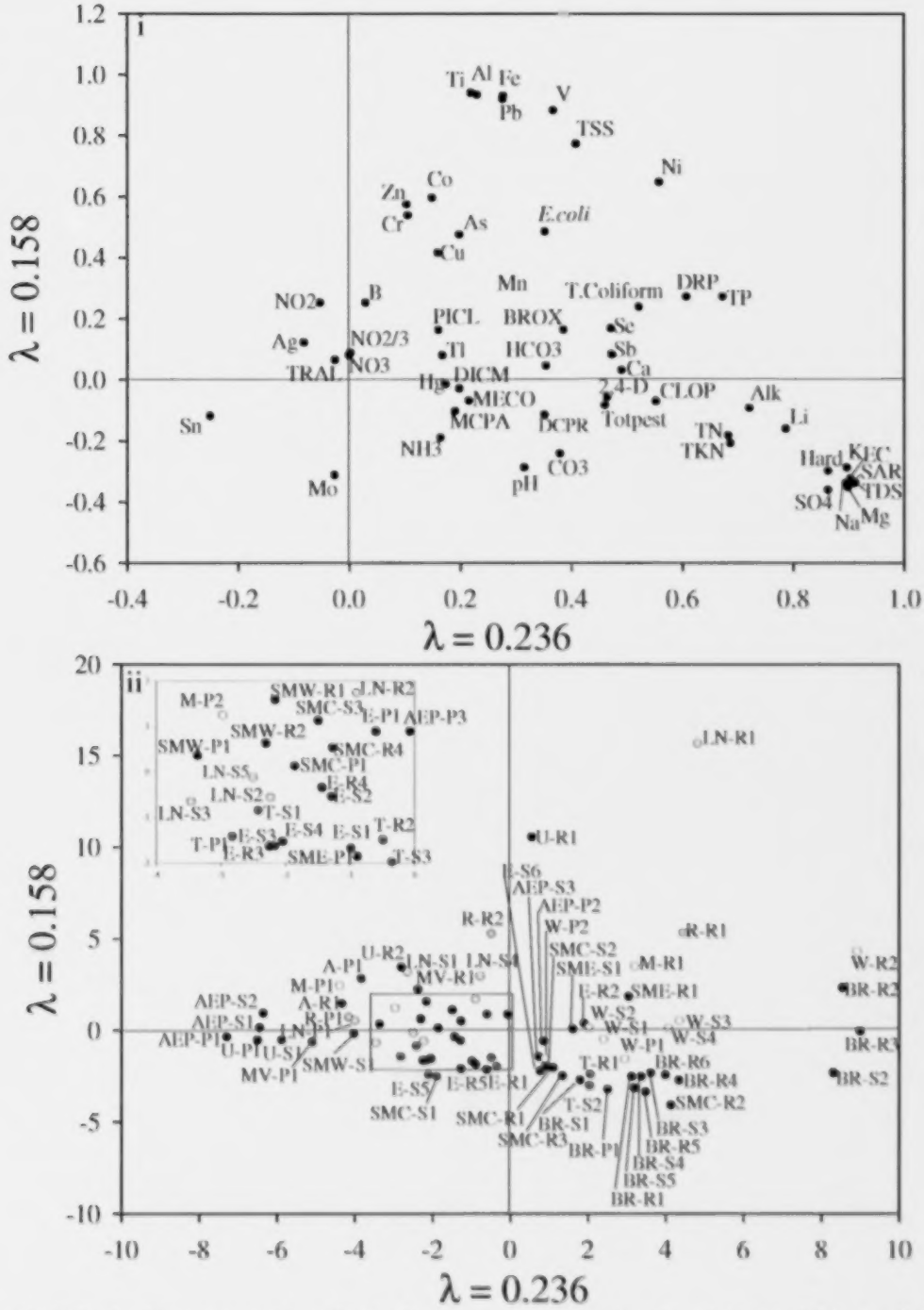

Fig. 3. Principal components analysis site scores for (i) water chemistry variables and (ii) 80 comprehensive sites.

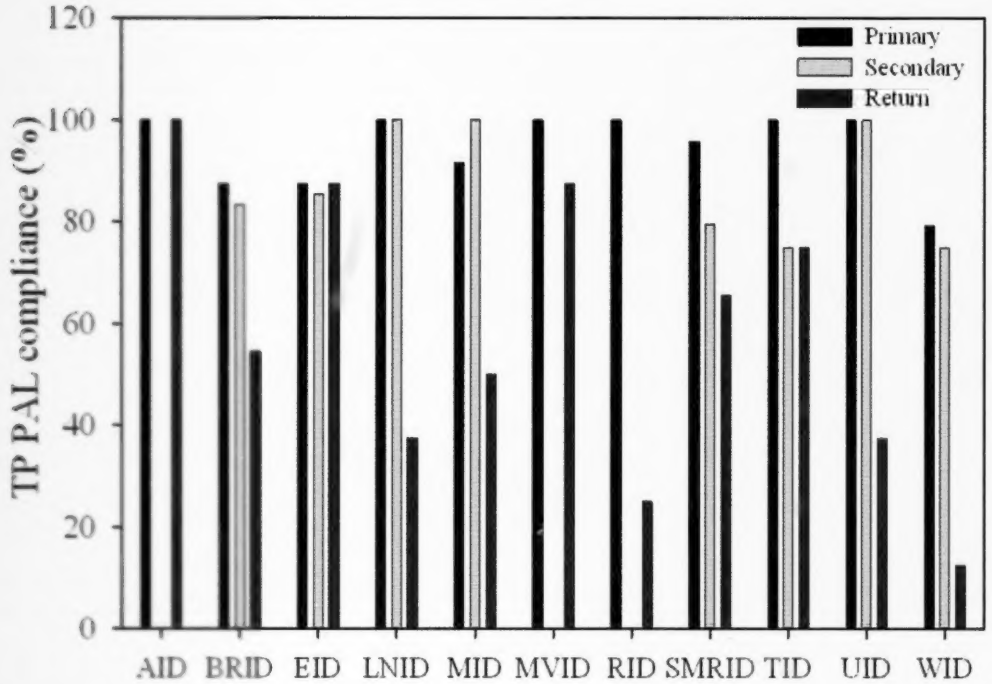

Fig. 4. Percent compliance of total phosphorus (TP) with Alberta guideline for the protection of aquatic life (PAL) (0.05 mg L^{-1}, Alberta Environment 1999) by irrigation district and site type.

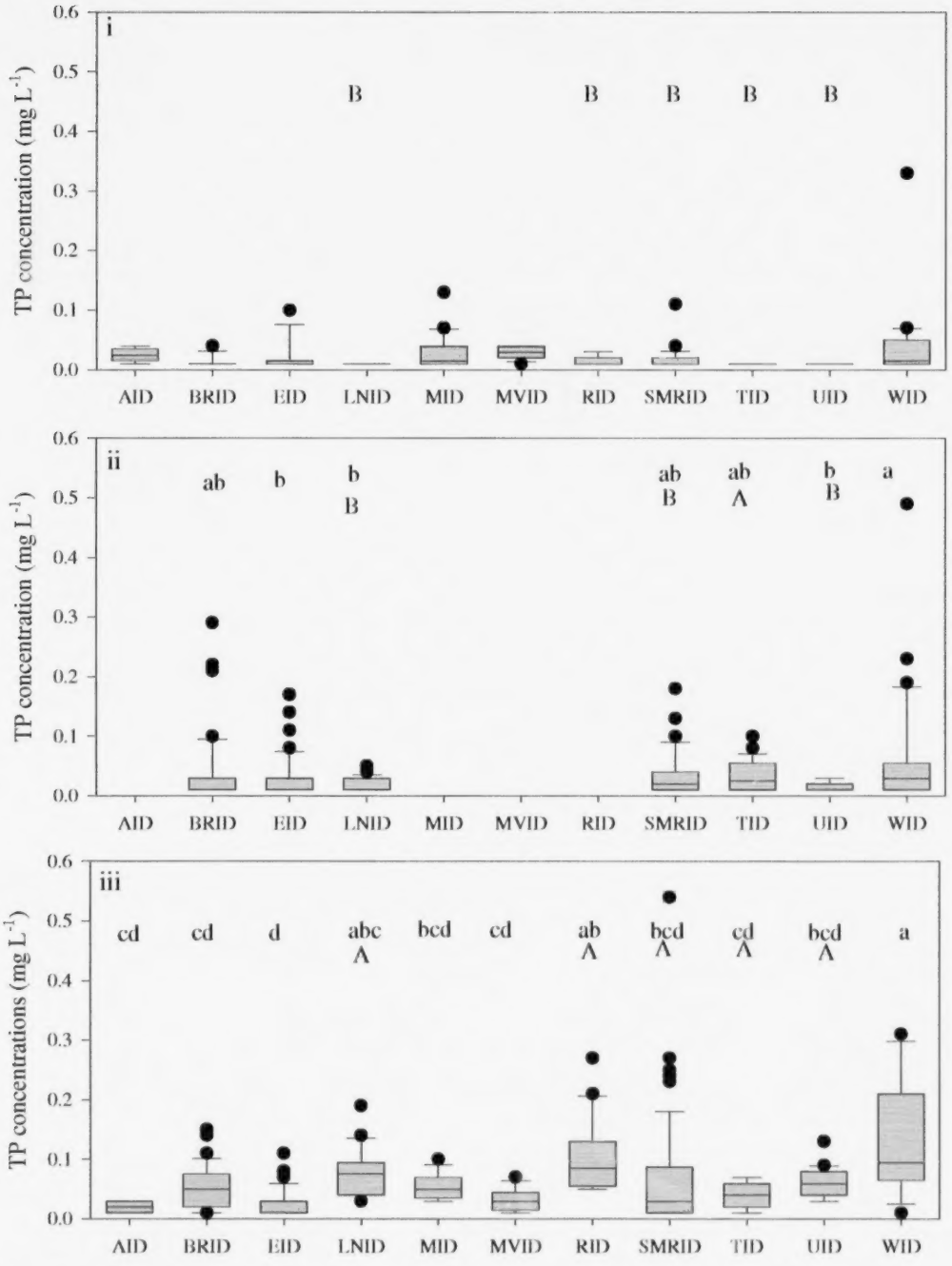

Fig. 5. Boxplots of total phosphorus (TP) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

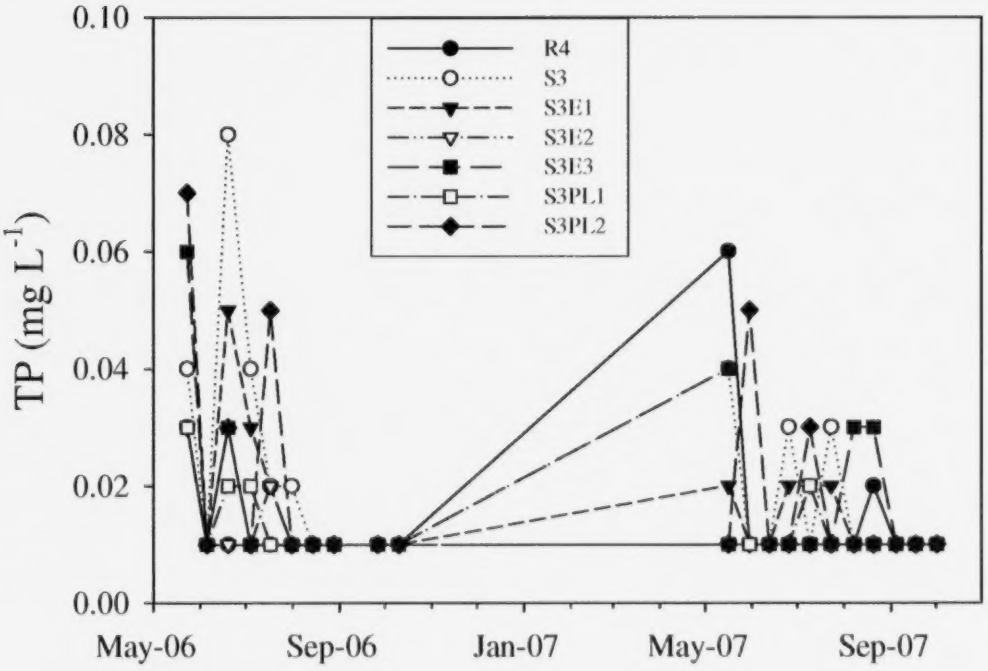

Fig. 6. Total phosphorus (TP) concentrations in the seven representative sites.

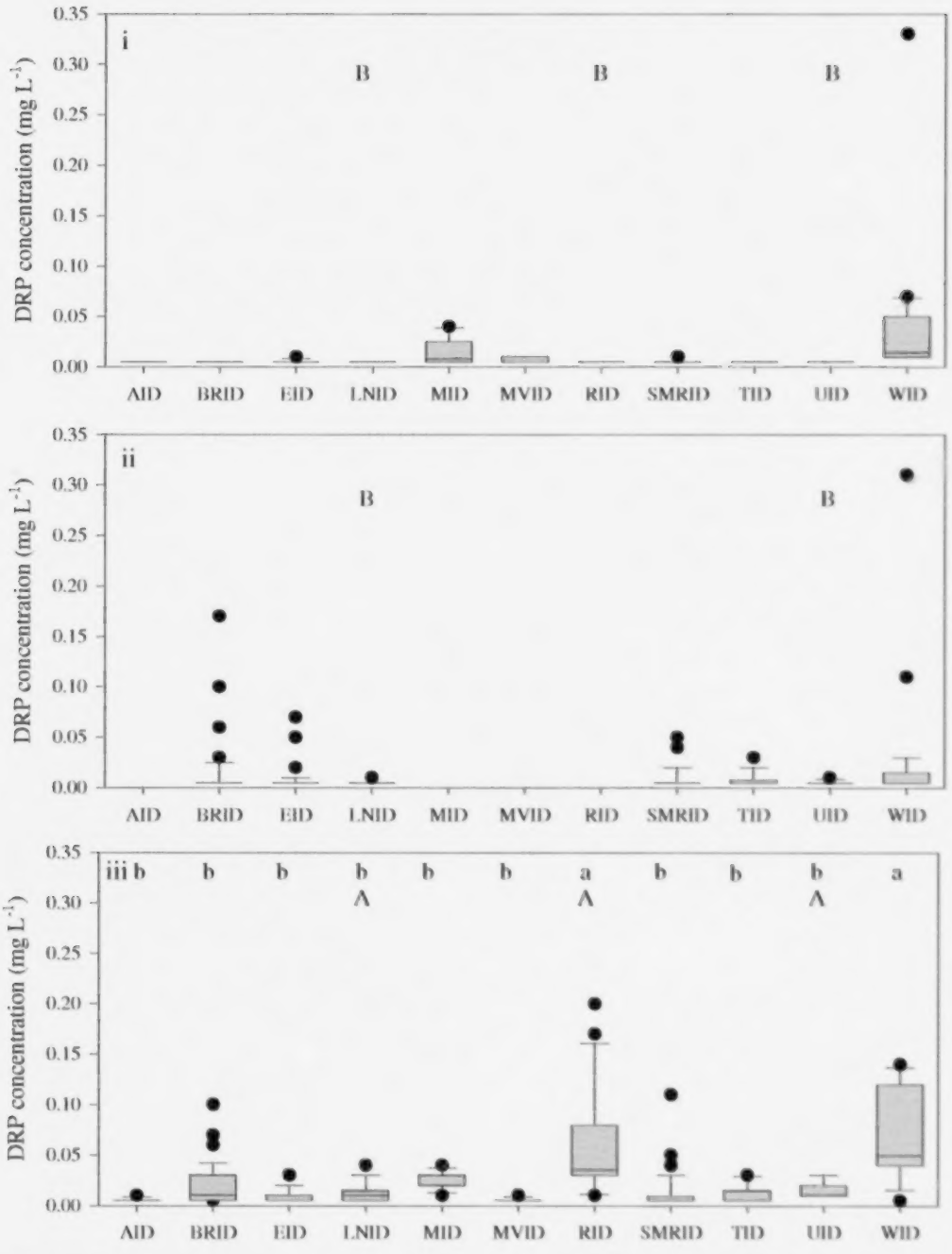

Fig. 7. Boxplots of dissolved reactive phosphorus (DRP) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

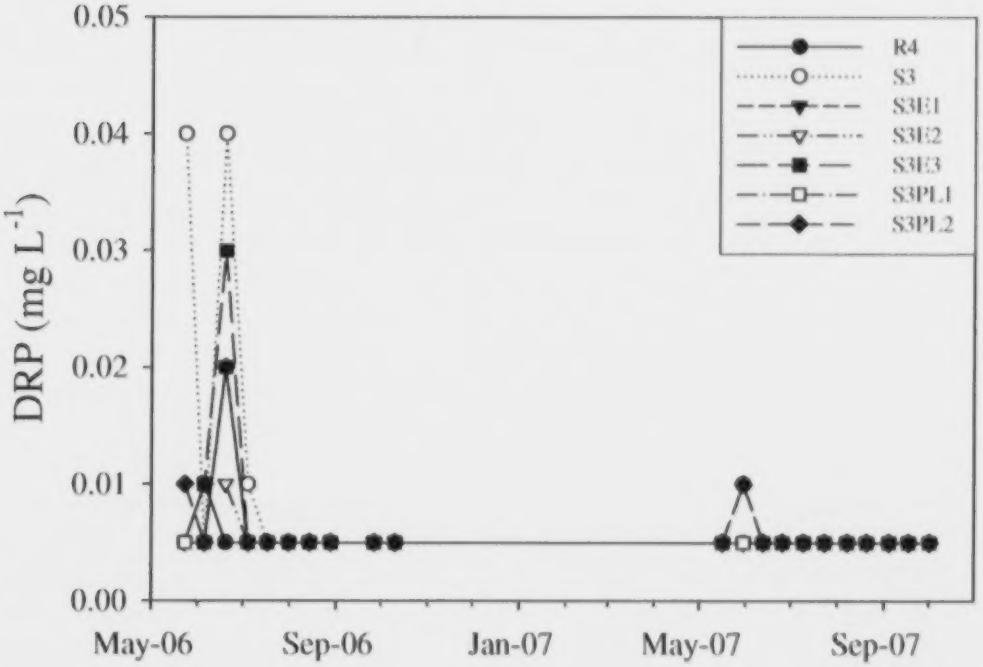

Fig. 8. Dissolved reactive phosphorus (DRP) concentrations in the seven representative sites.

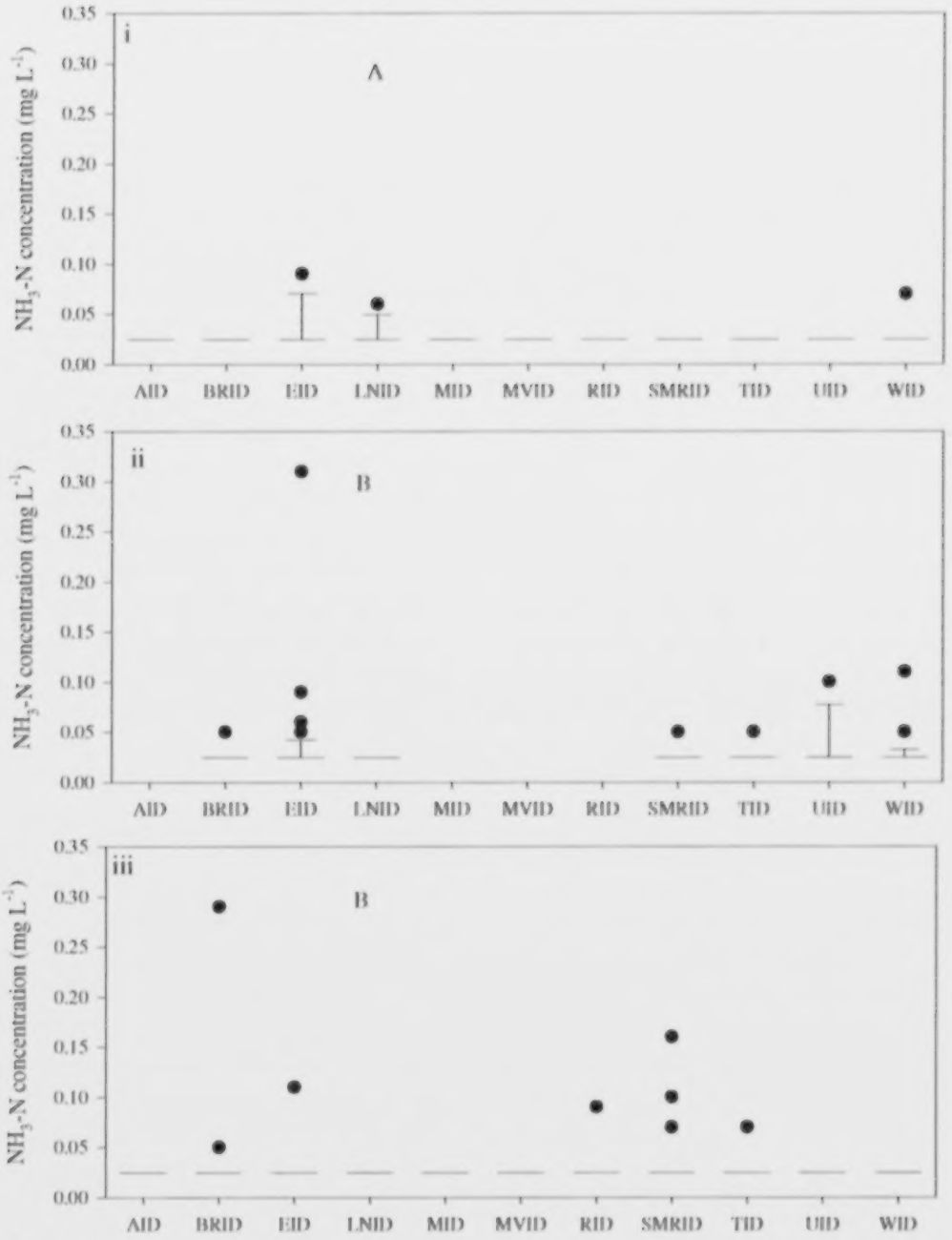

Fig. 9. Boxplots of ammonia-N (NH_3-N) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different uppercase letters are significantly different within each irrigation district (vertical comparison) at $p<0.05$.

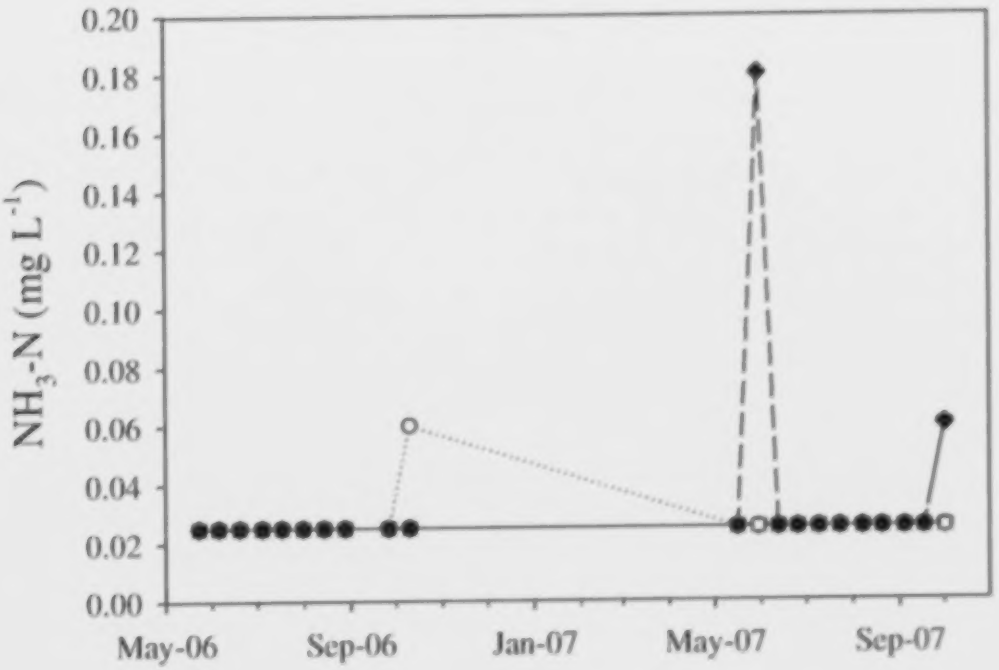

Fig. 10. Ammonia-N concentrations in the seven representative sites.

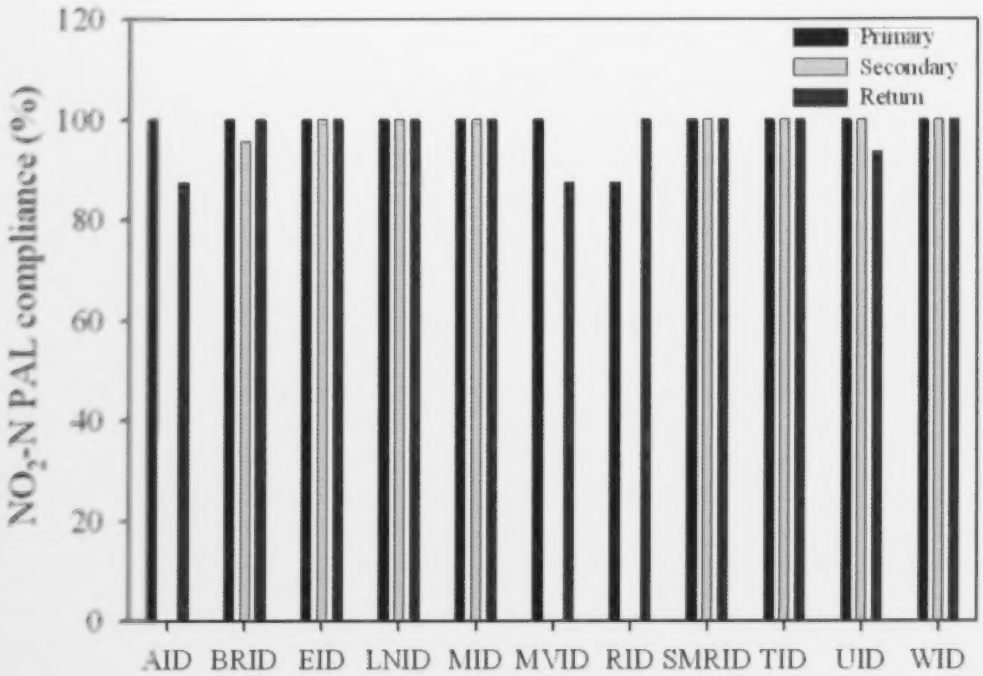

Fig. 11. Percent compliance with CCME nitrite-N (NO_2-N) guidelines for the protection of aquatic life (PAL) (0.06 mg L^{-1}, CCREM 1987) by irrigation district.

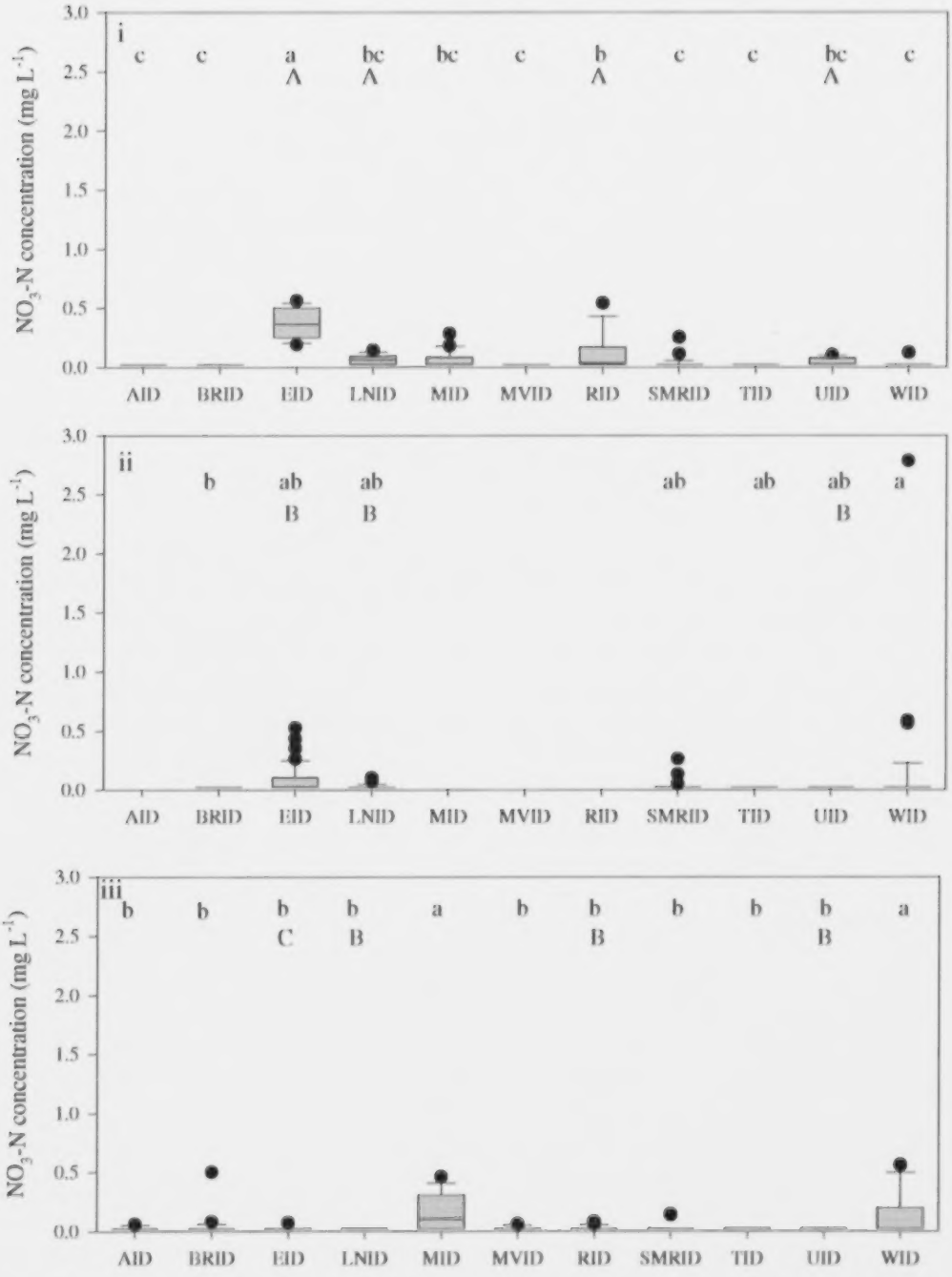

Fig. 12. Boxplots of nitrate-N (NO_3-N) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

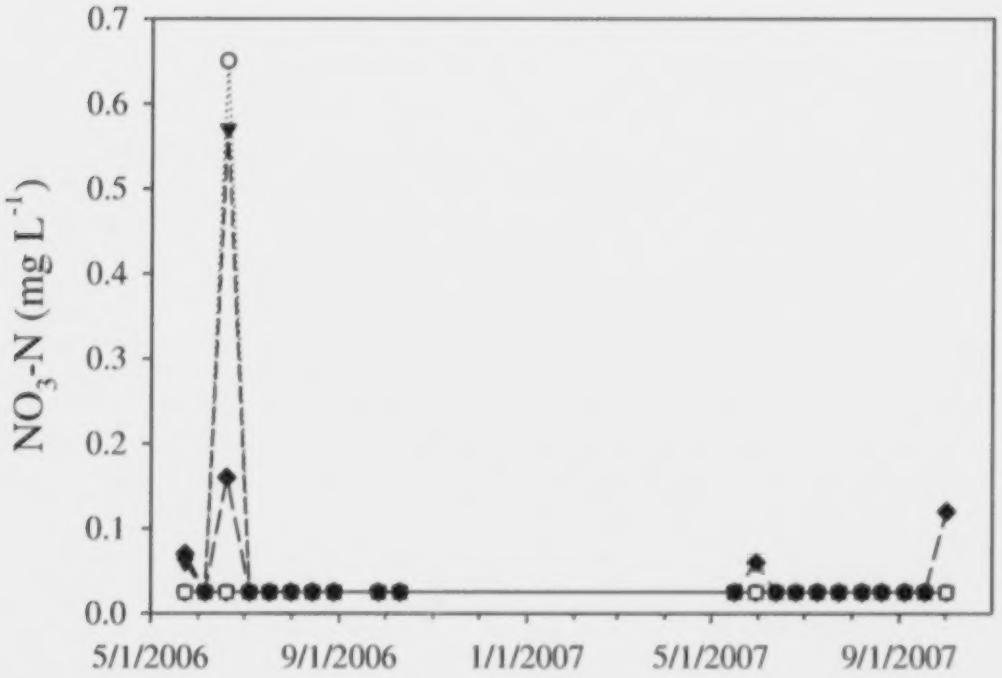

Fig. 13. Nitrate-N (NO_3-N) concentrations in the seven representative sites.

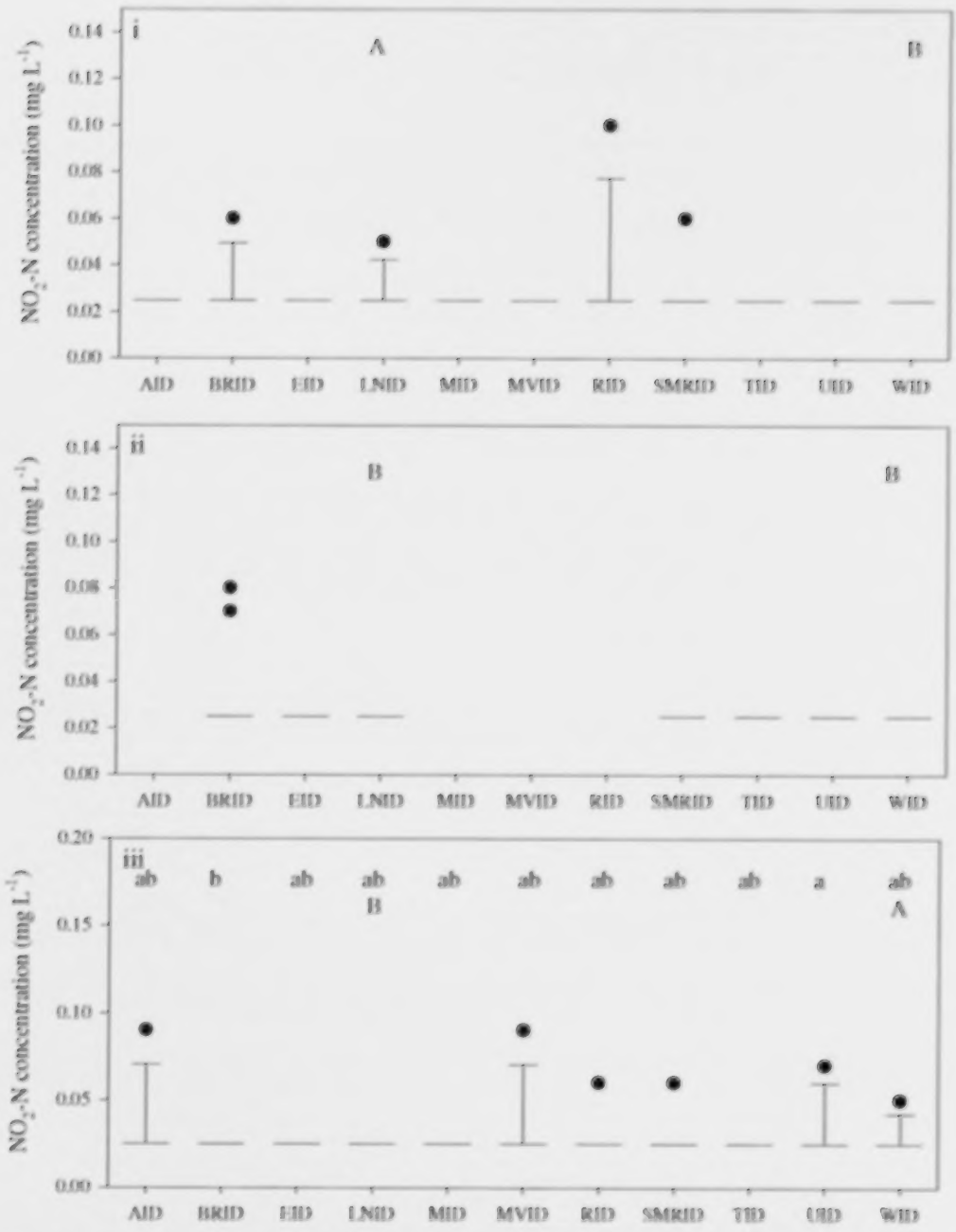

Fig. 14. Boxplots of nitrite-N (NO_2-N) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

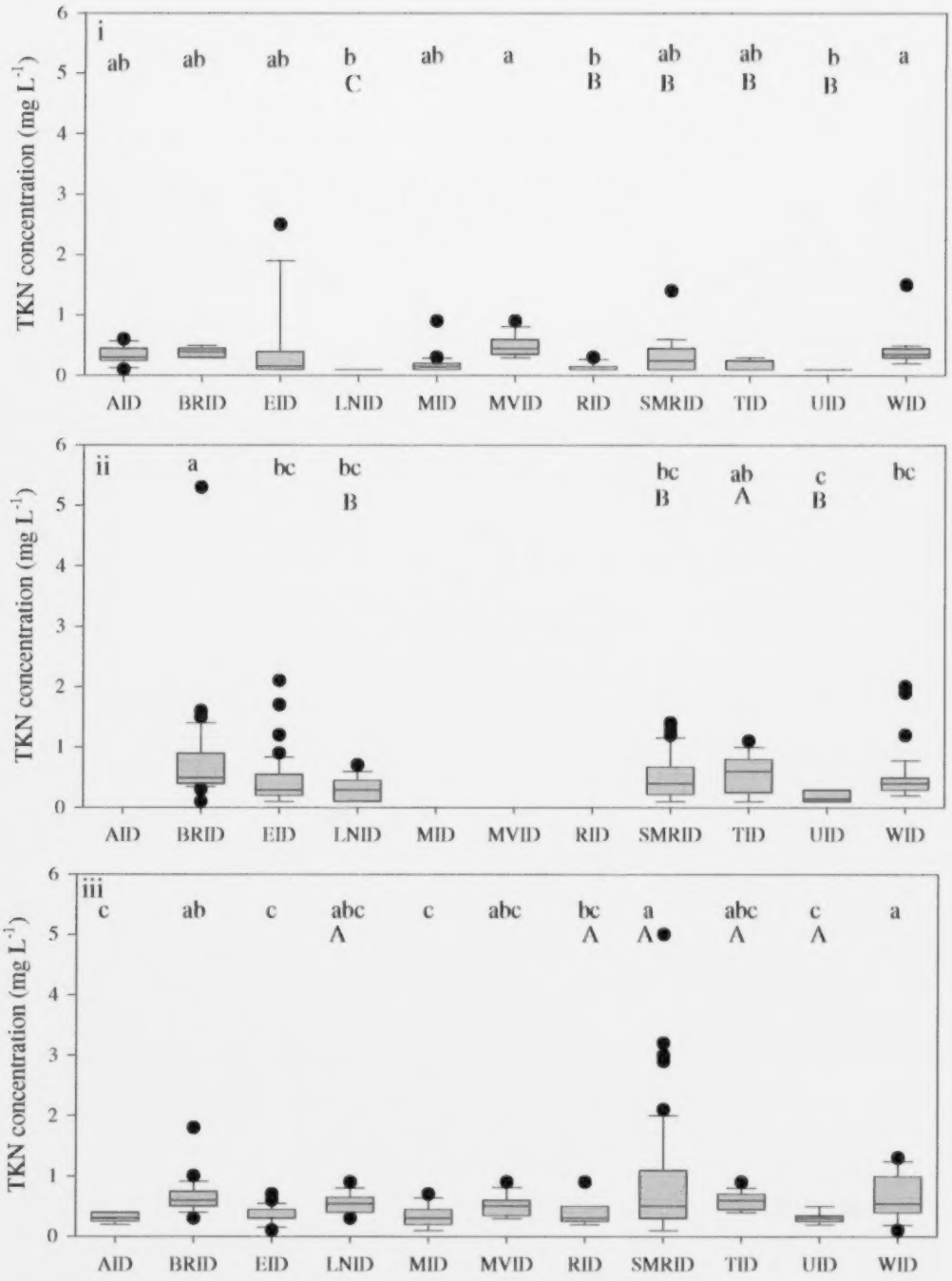
i
ab ab ab b ab a b ab ab b a
C B B B B
ii
a bc bc bc ab c bc
B B A B
iii
c ab c abc c abc bc a abc c a
A A A A A
TKN concentration (mg L-1)
0 1 2 3 4 5 6
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 15. Boxplots of total Kjeldahl nitrogen (TKN) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

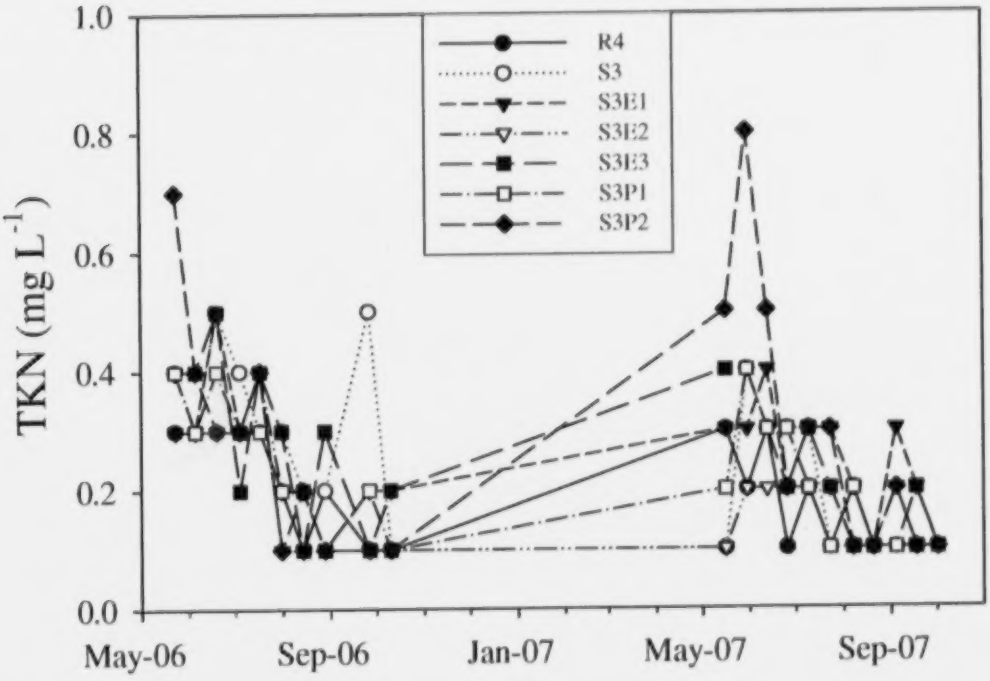

Fig. 16. Total Kjeldahl nitrogen (TKN) concentrations in the seven representative sites.

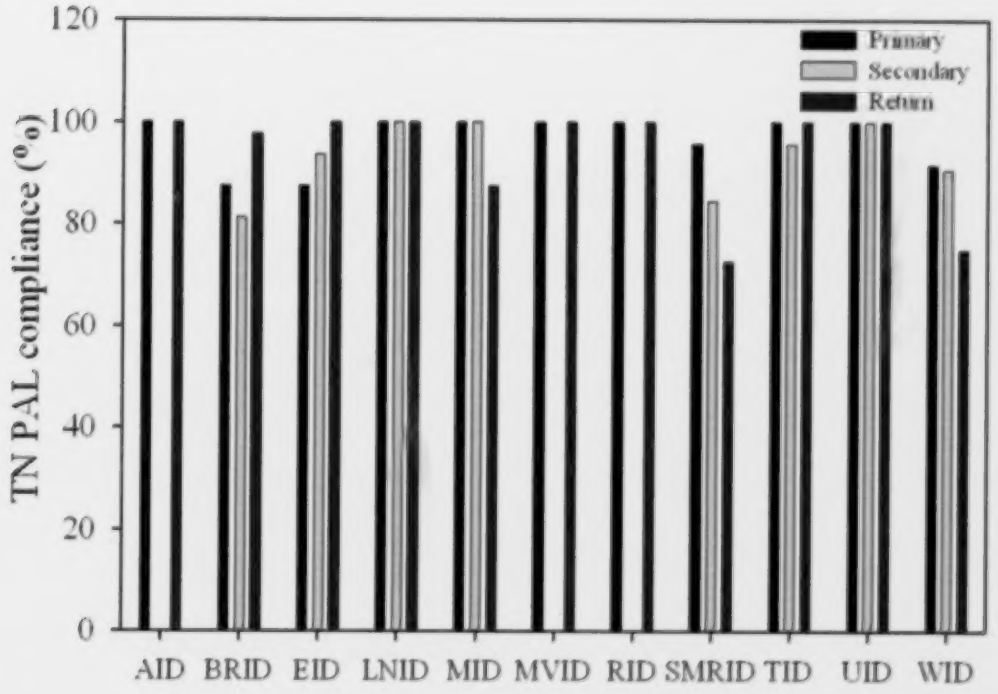

Fig. 17. Percent compliance of total nitrogen (TN) with the Alberta water quality guideline for the protection of aquatic life (PAL) (1.0 mg L^{-1}, Alberta Environment 1999).

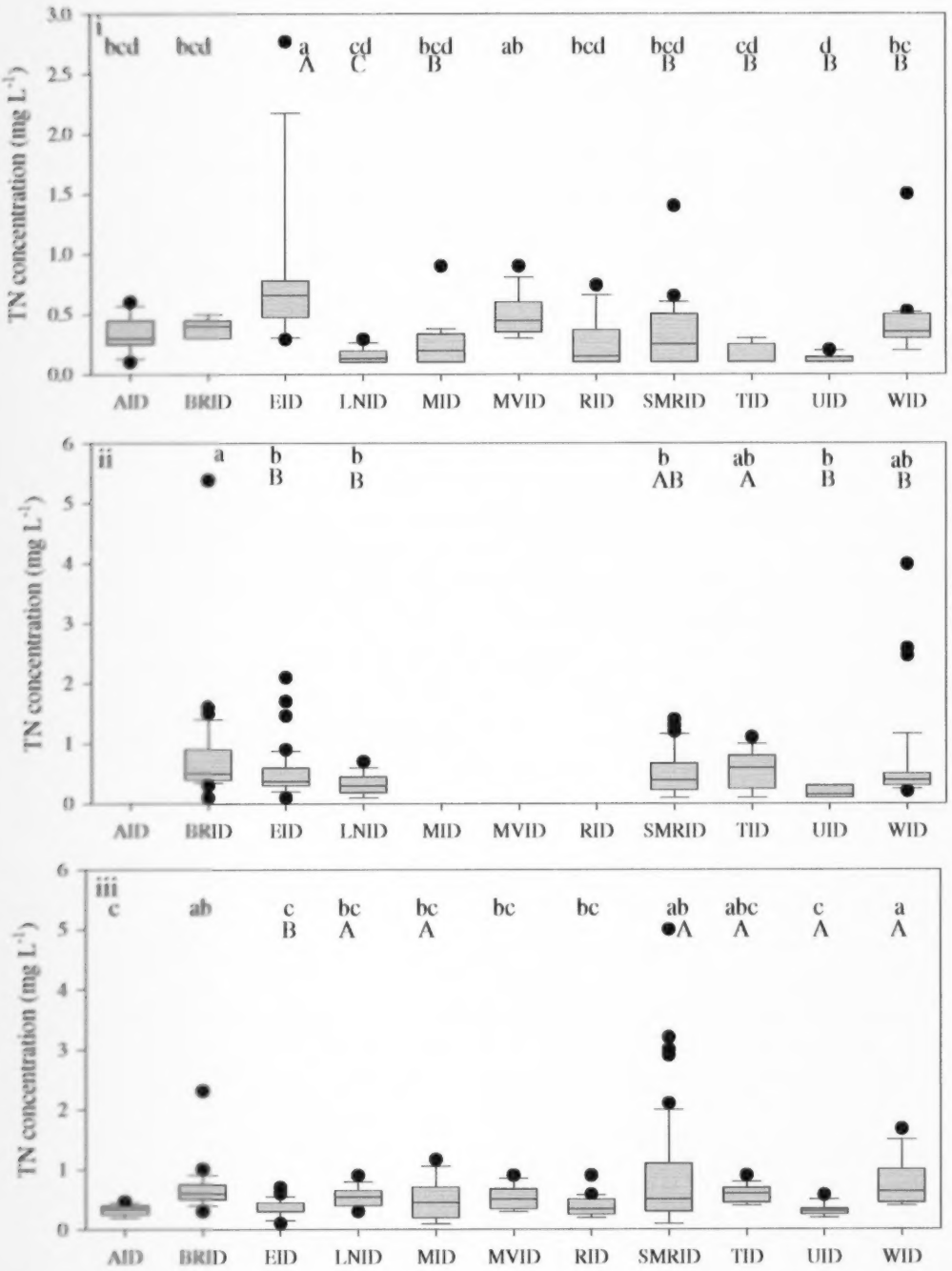

Fig. 18. Boxplots of total nitrogen (TN) concentration in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

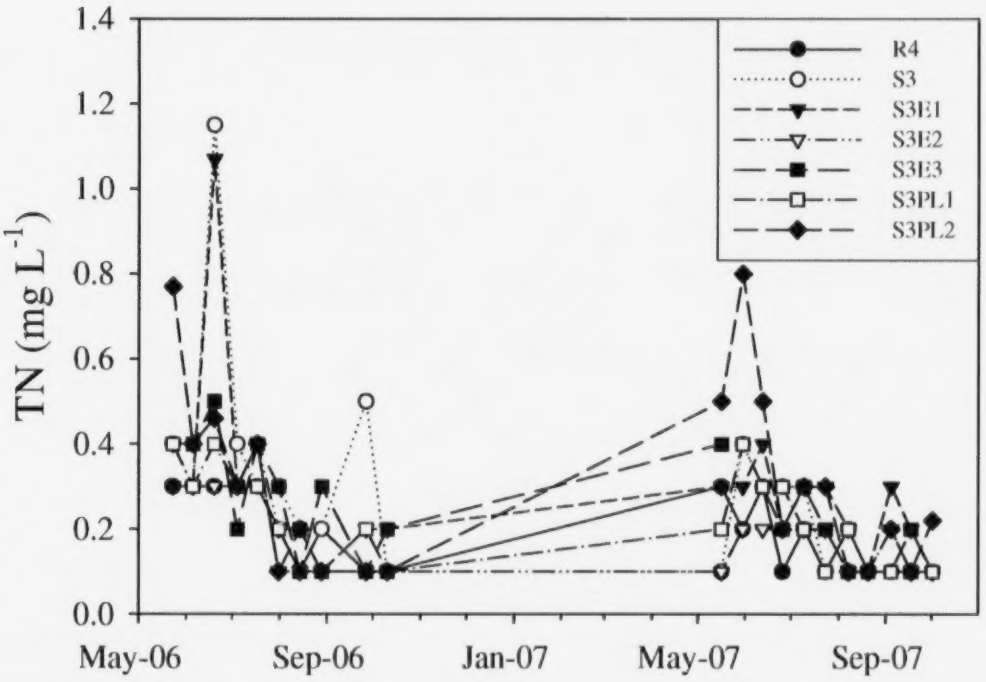

Fig. 19. Total nitrogen (TN) concentrations at the seven representative sites.

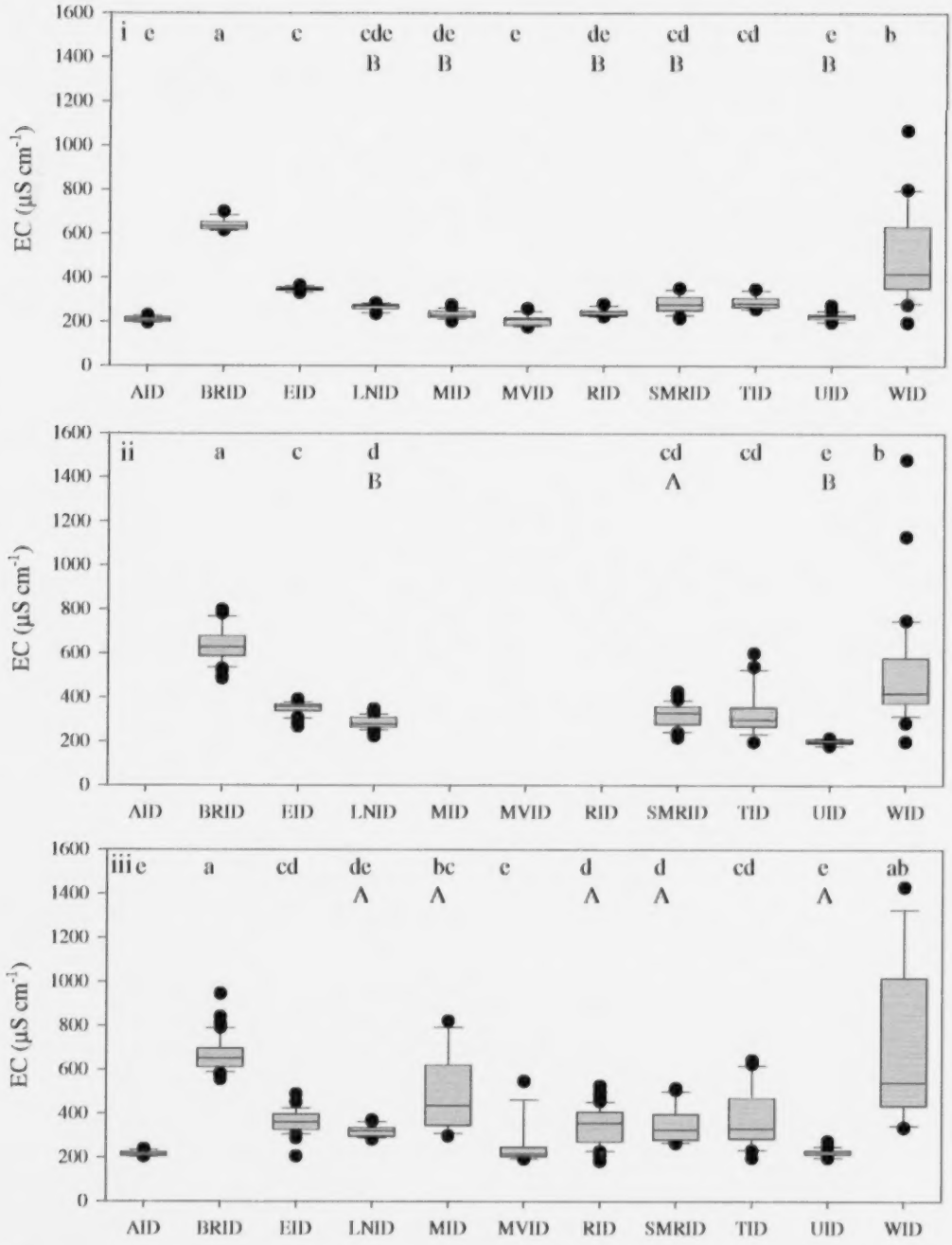
i e a c cde de e de cd cd e b
B B B B B
ii a c d cd cd e b
B A B
iii e a cd de bc e d d cd e ab
A A A A A
EC (µS cm-1)
0 200 400 600 800 1000 1200 1400 1600
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 20. Boxplots of electrical conductivity (EC) in (i) primary, (ii) secondary, and (iii) return flow sites. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

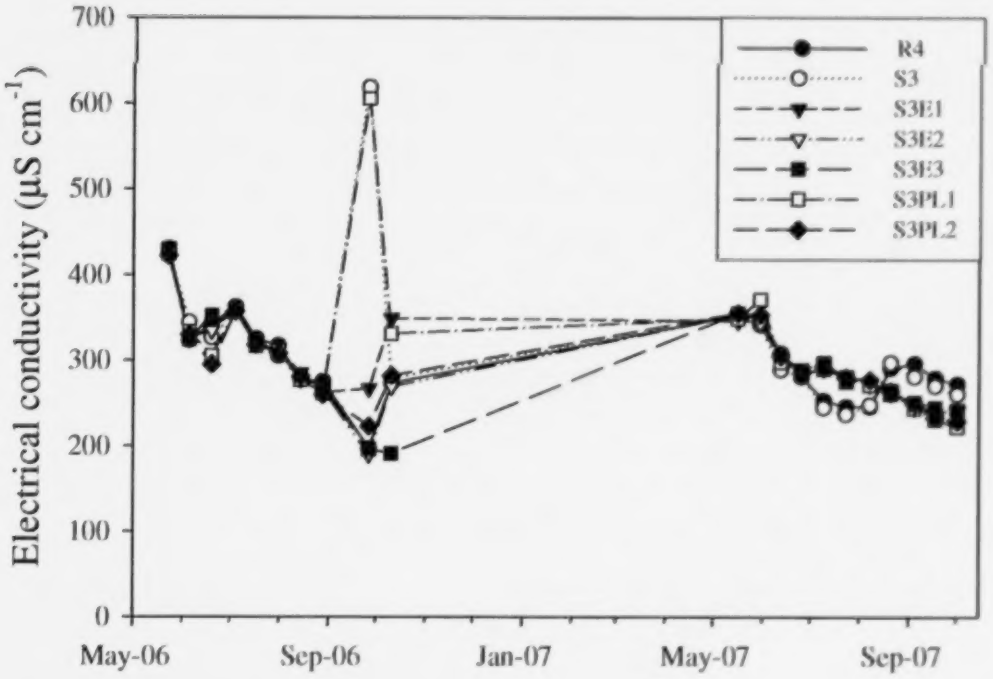

Fig. 21. Electrical conductivity at the seven representative sites.

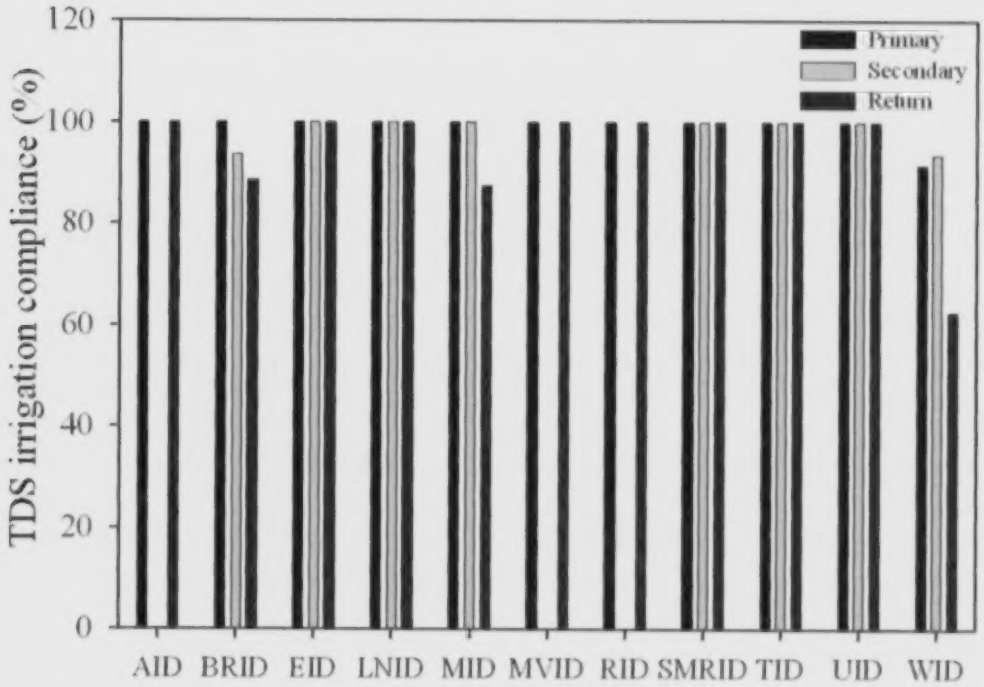

Fig. 22. Percent compliance with the lowest CCME irrigation guideline of 500 mg L^{-1} (CCREM 1987) for total dissolved solids (TDS).

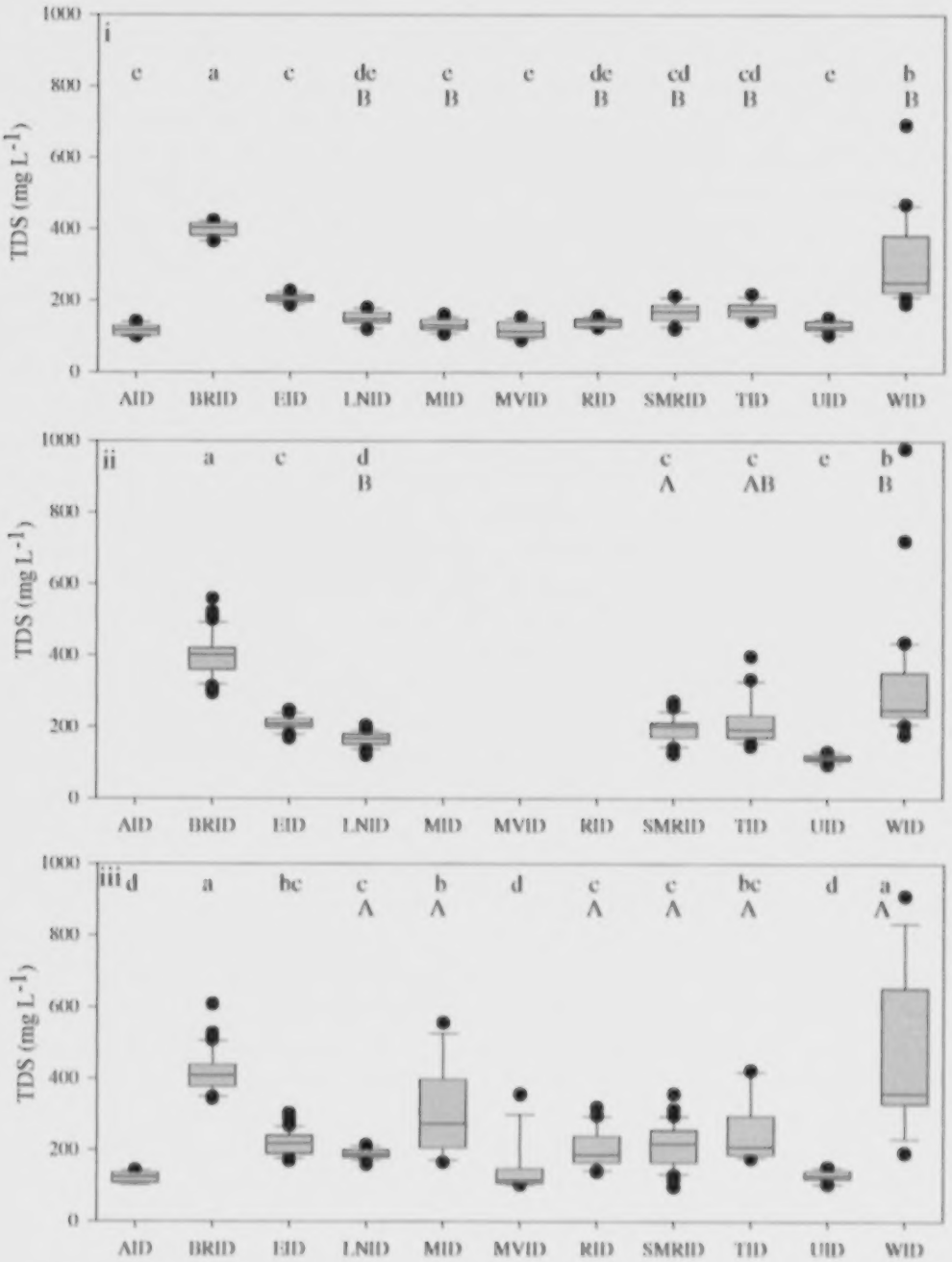

Fig. 23. Boxplots of total dissolved solids (TDS) in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

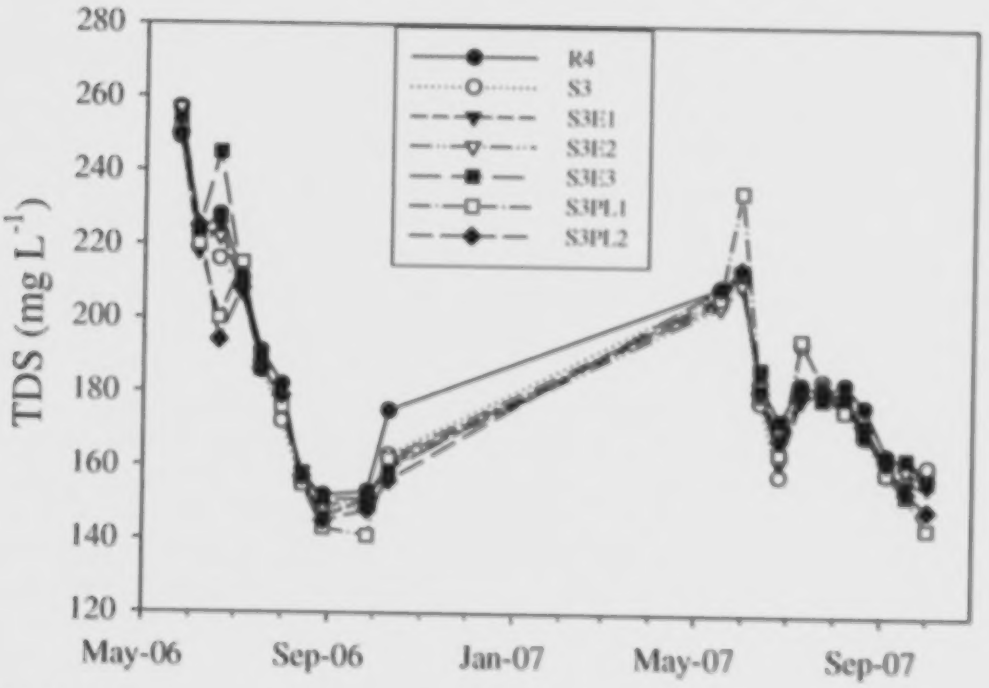

Fig. 24. Total dissolved solids (TDS) for the seven representative sites.

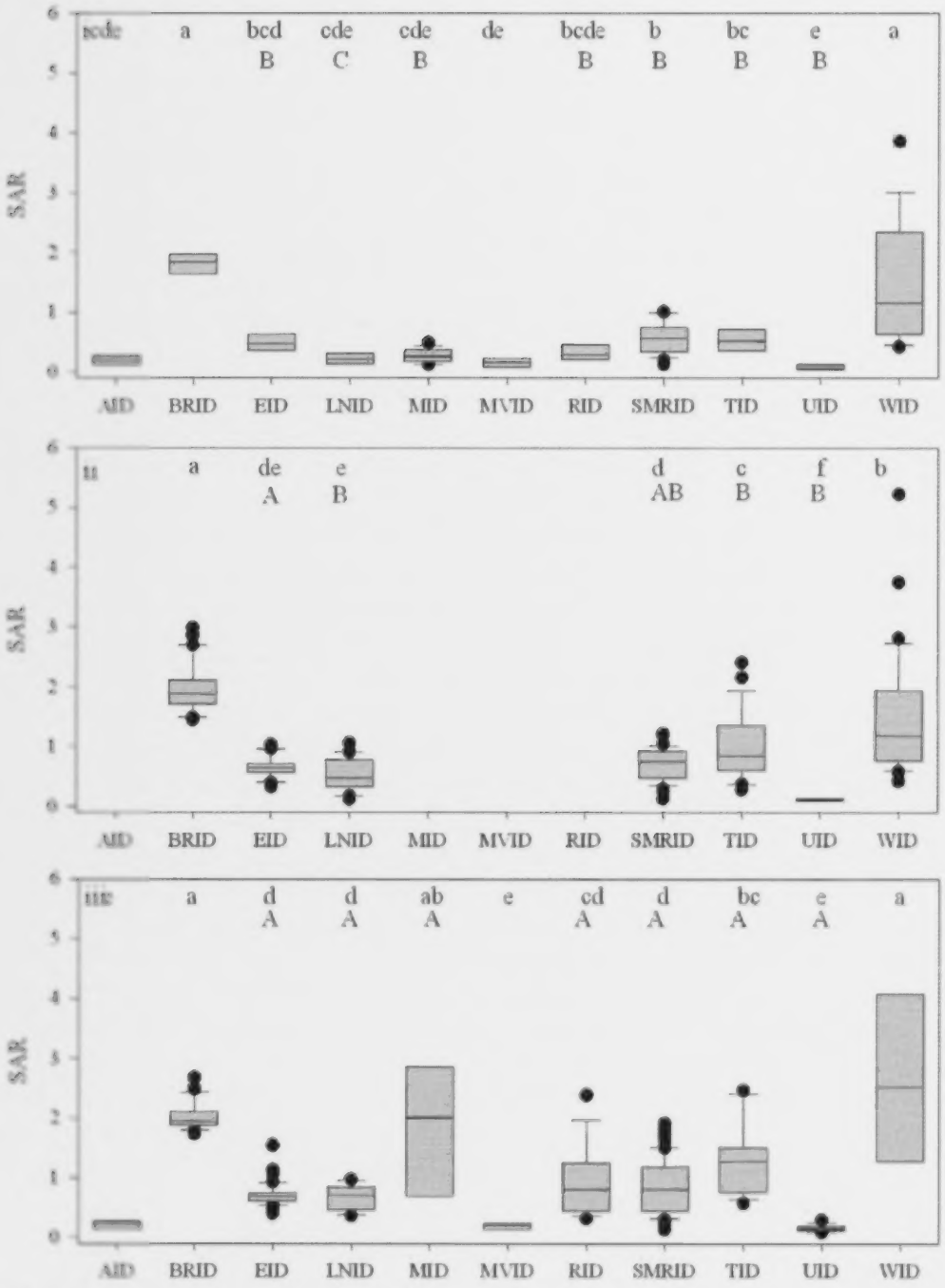
SAR
AID BRID EID LNID MID MVID RID SMRID TID UID WID
a bcd cde cde de bcde b bc e a
B C B B B B B
de e d c f b
A B AB B B
a d d ab e cd d bc e a
A A A A A A A

Fig. 25. Boxplots of sodium adsorption ratio (SAR) in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

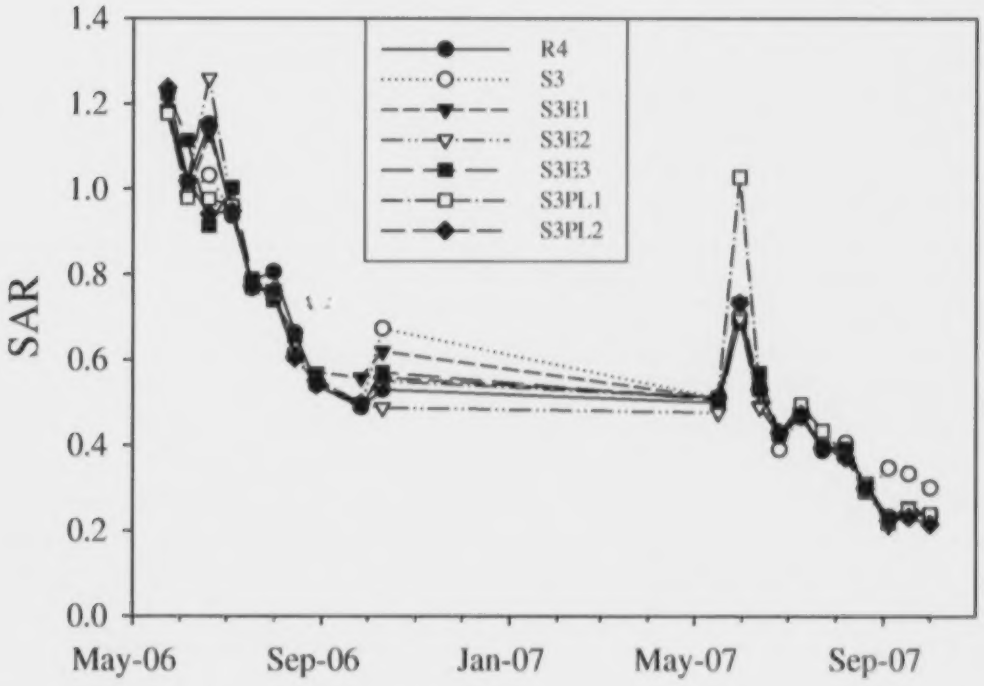

Fig. 26. Sodium adsorption ratio (SAR) at the seven representative sites.

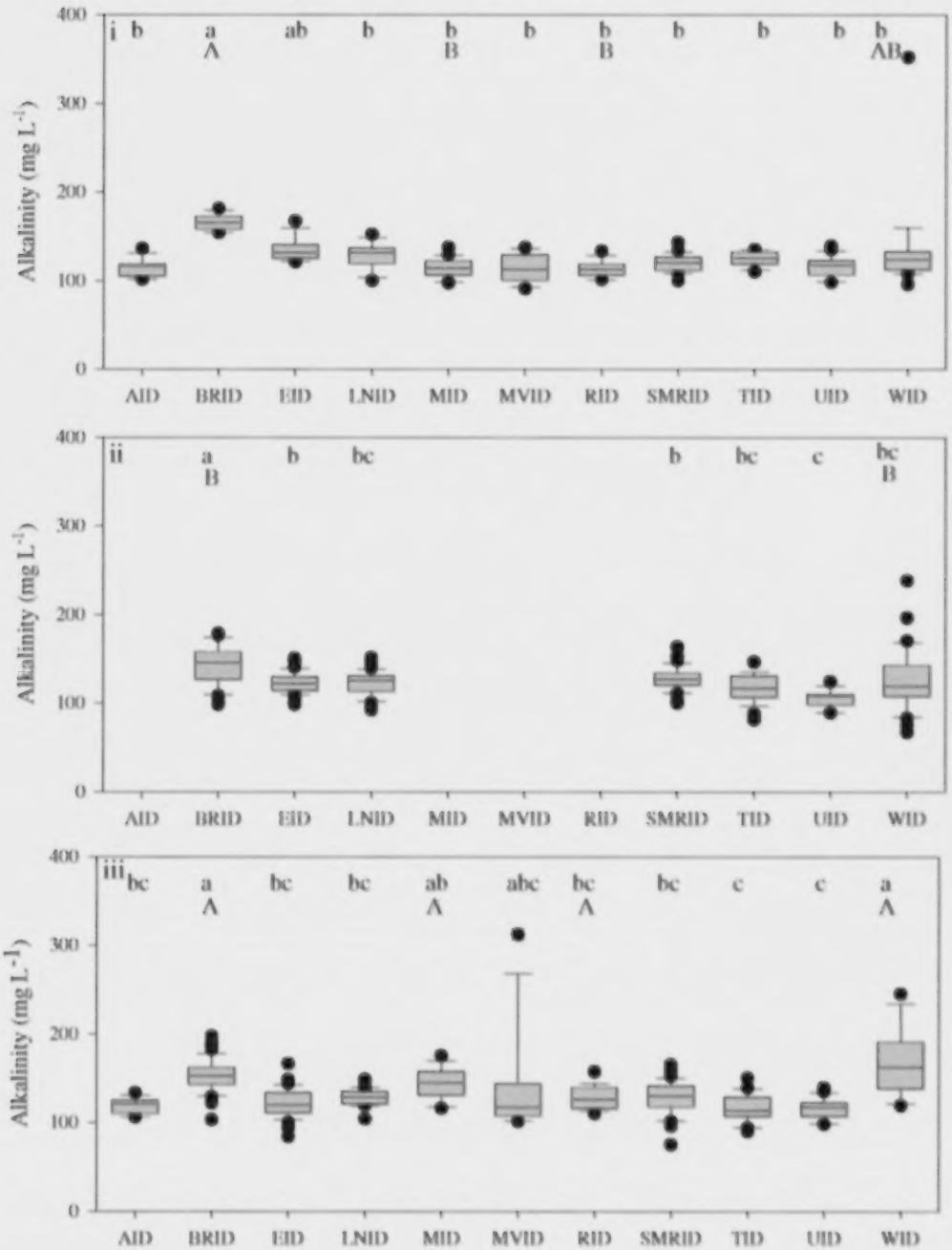

Fig. 27. Boxplots of alkalinity in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

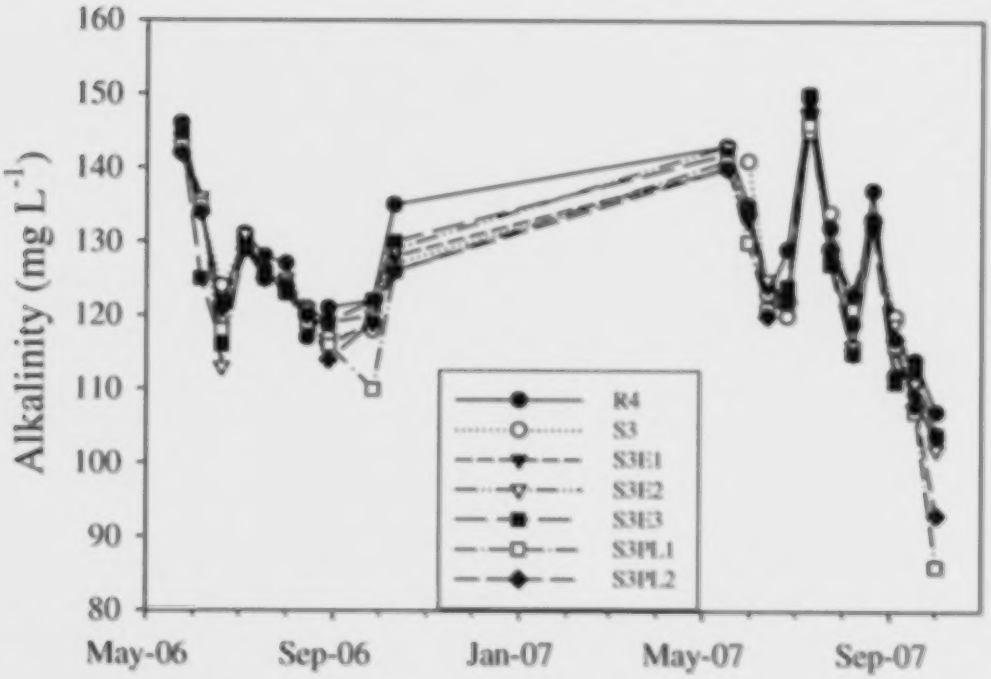

Fig. 28. Alkalinity at the seven representative sites.

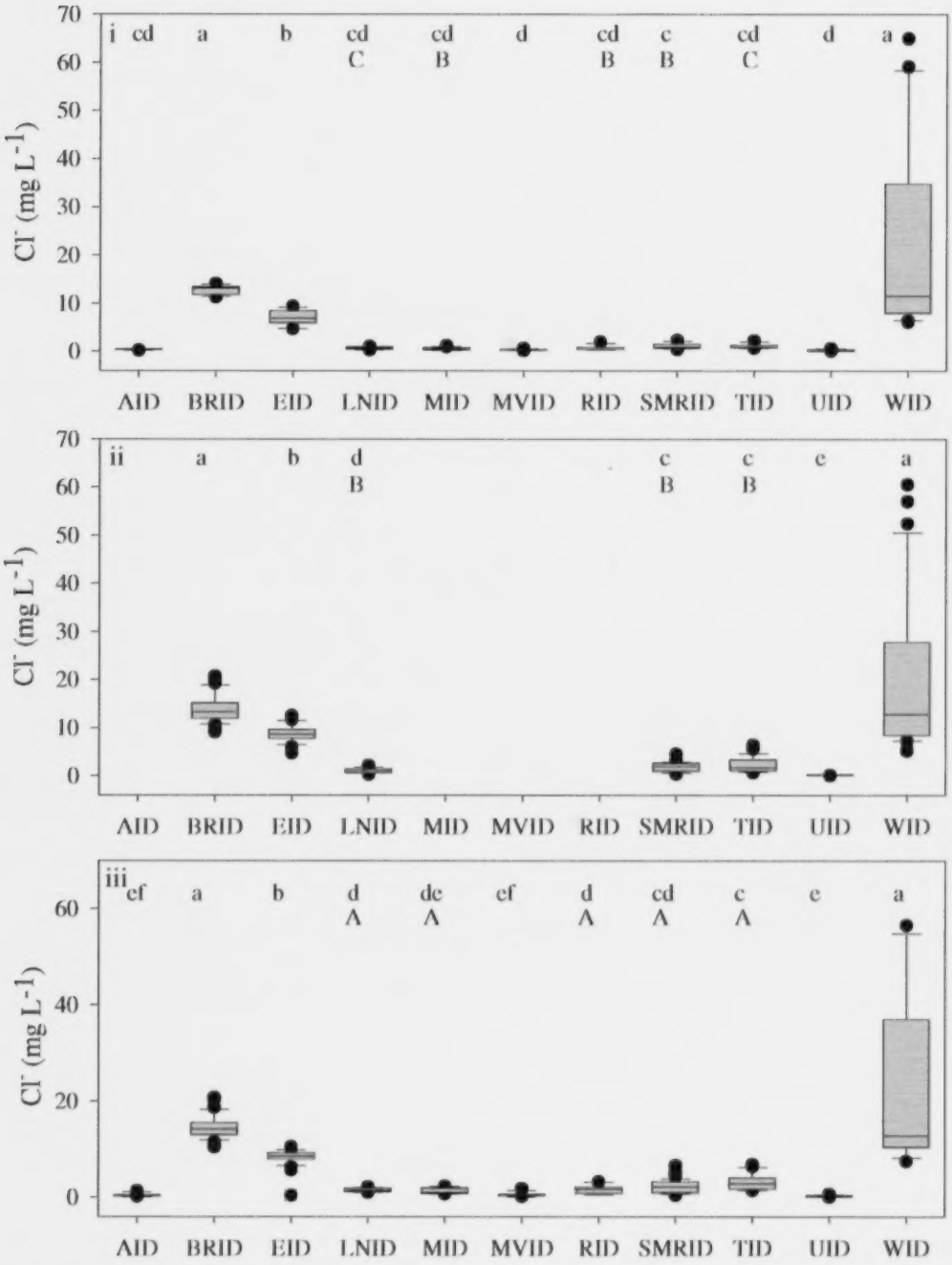

Fig. 29. Boxplots of chloride (Cl^-) in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

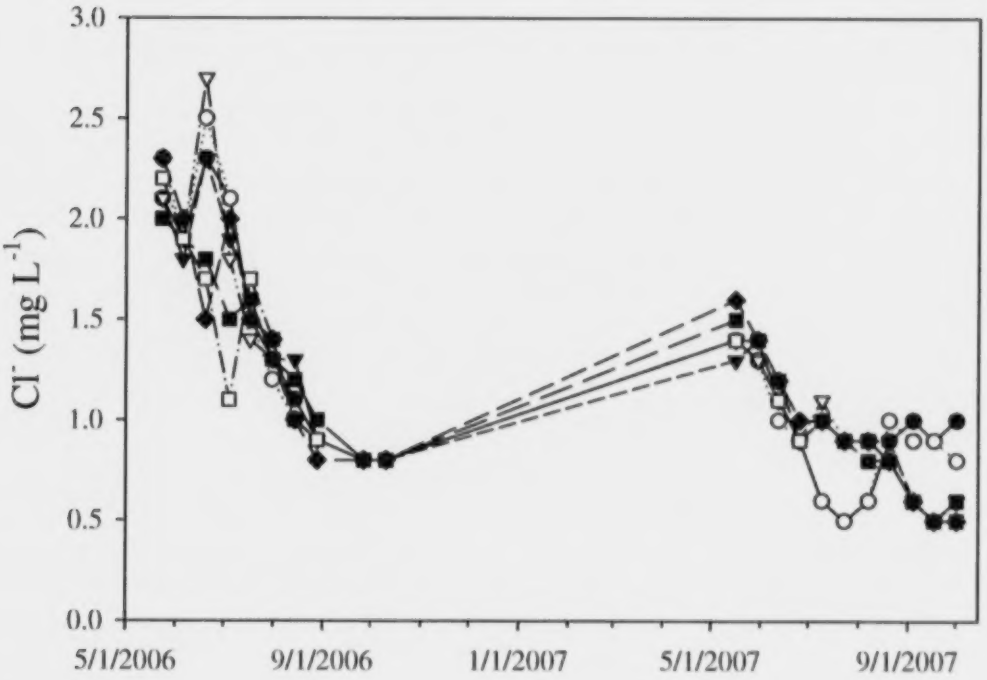

Fig. 30. Chloride (Cl^-) concentrations at the seven representative sites.

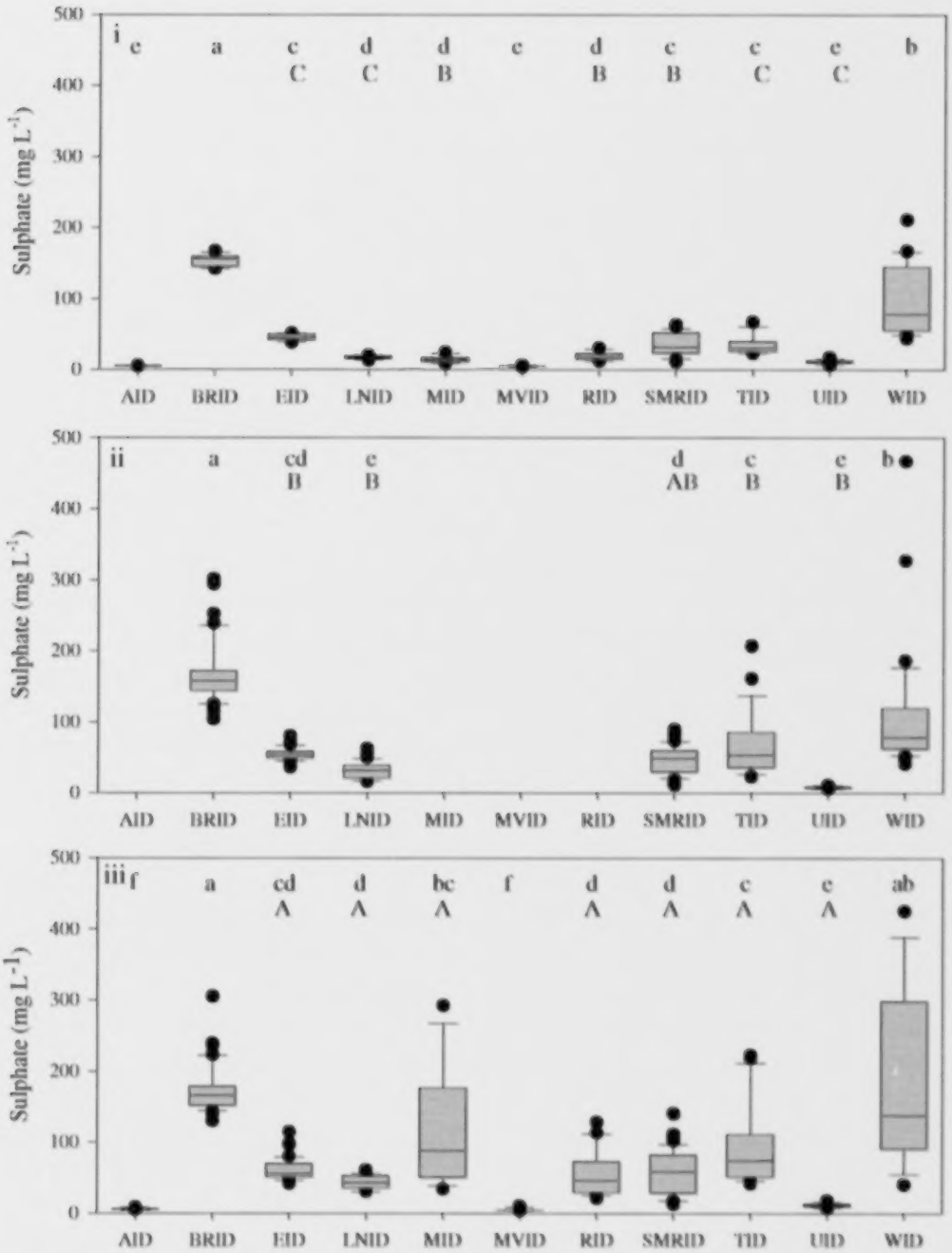

Fig. 31. Boxplots of sulphate in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

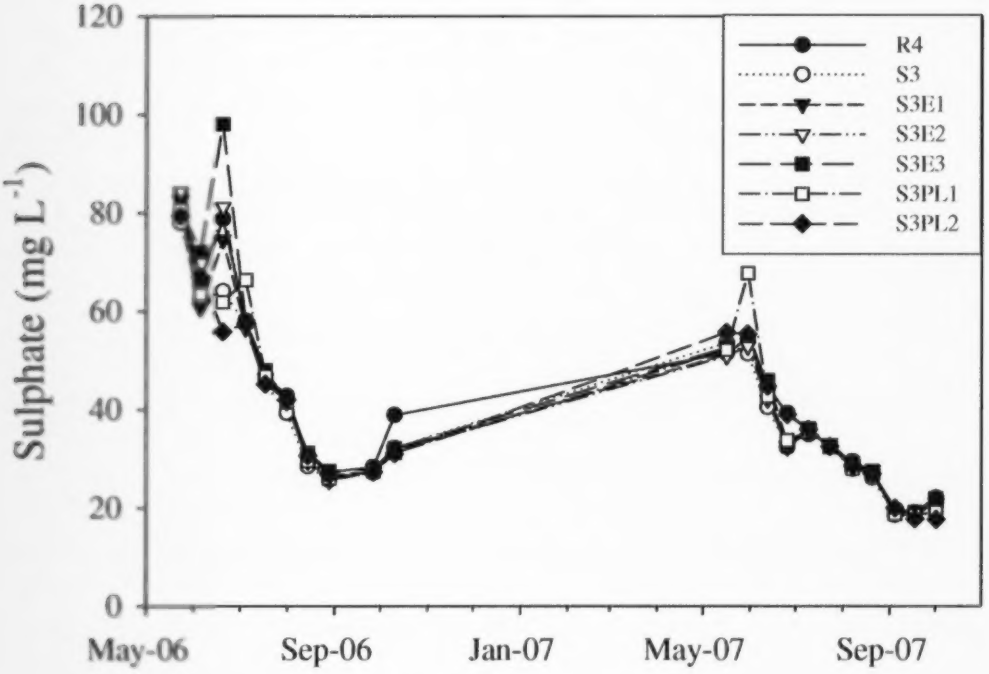

Fig. 32. Sulphate concentrations at the seven representative sites.

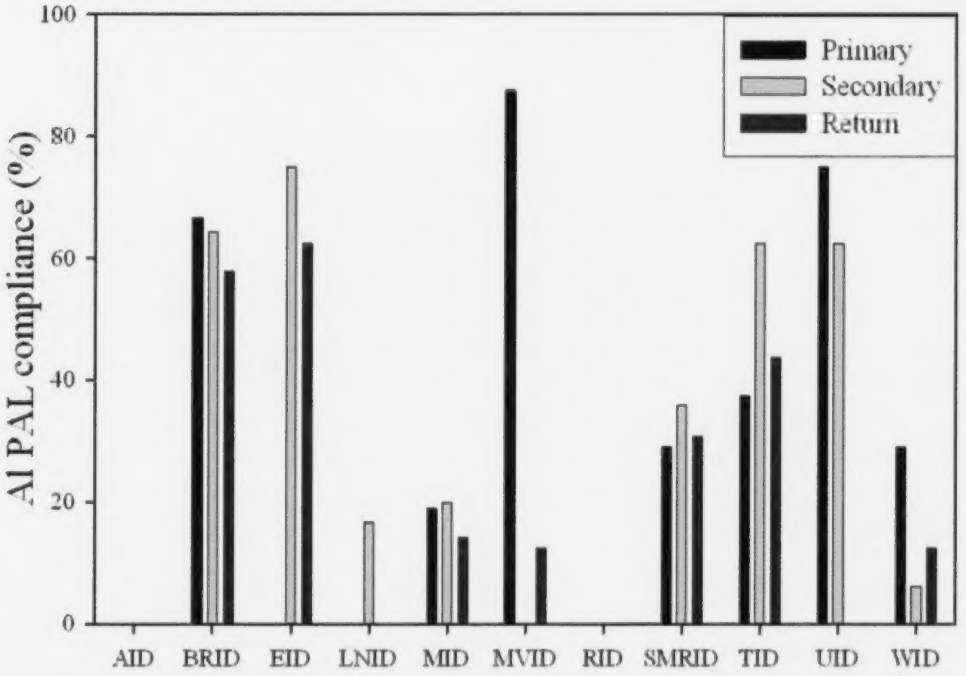

Fig. 33. Percent compliance with CCME aluminum (Al) guidelines for the protection of aquatic life (PAL) (0.1 mg L^{-1}, CCREM 1987) by irrigation district and site type.

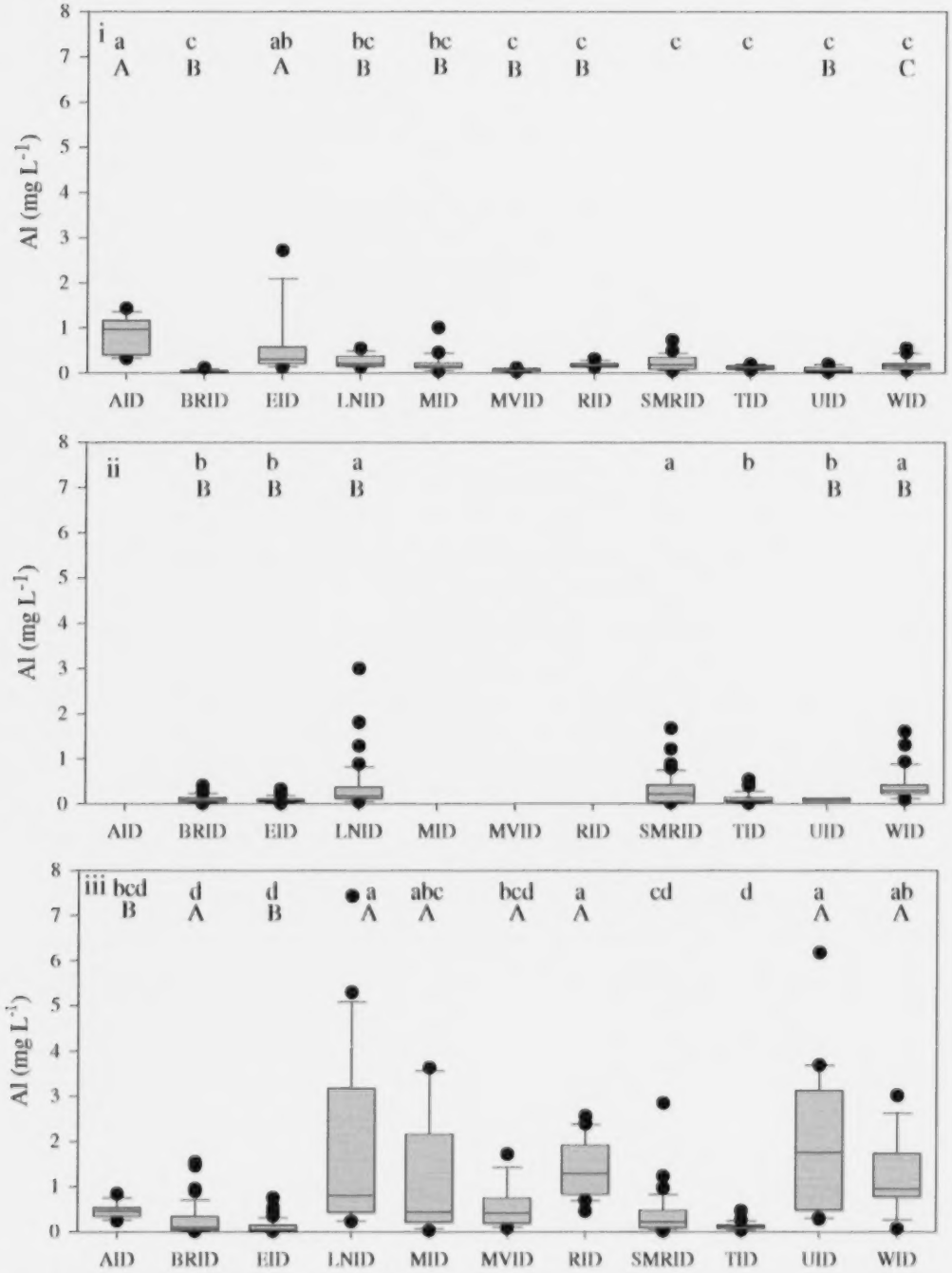
i
a c ab bc bc c c c c c c
A B A B B B B B
ii
b b a a b b a
B B B B B
iii bcd d d a abc bcd a cd d a ab
B A B A A A A A A
Al (mg L-1)
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 34. Boxplots of aluminum (Al) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

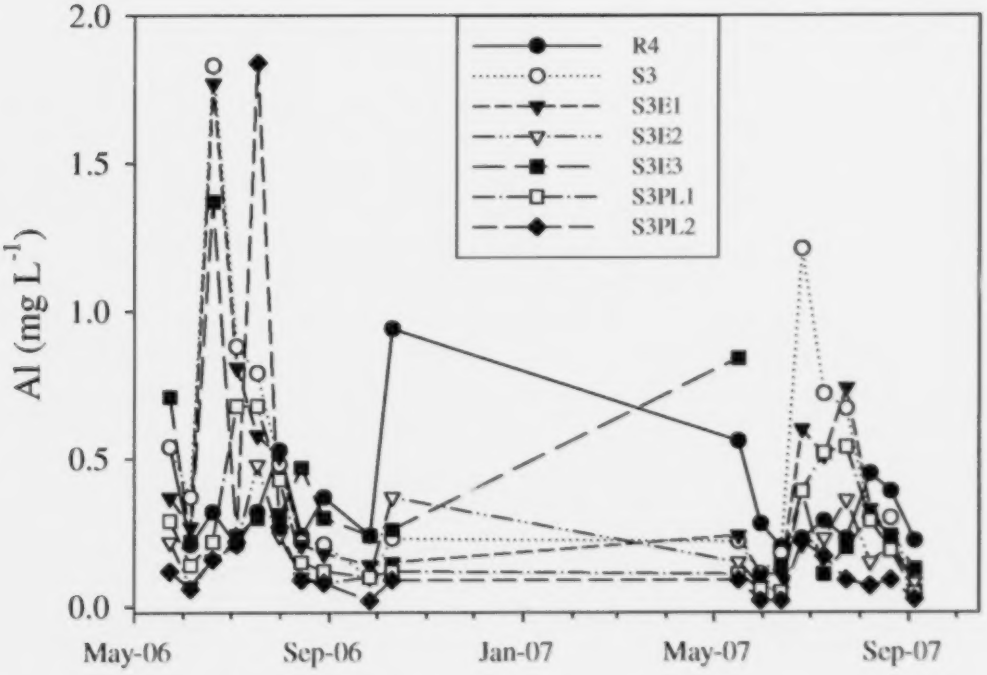

Fig. 35. Aluminum (Al) concentrations at the seven representative sites.

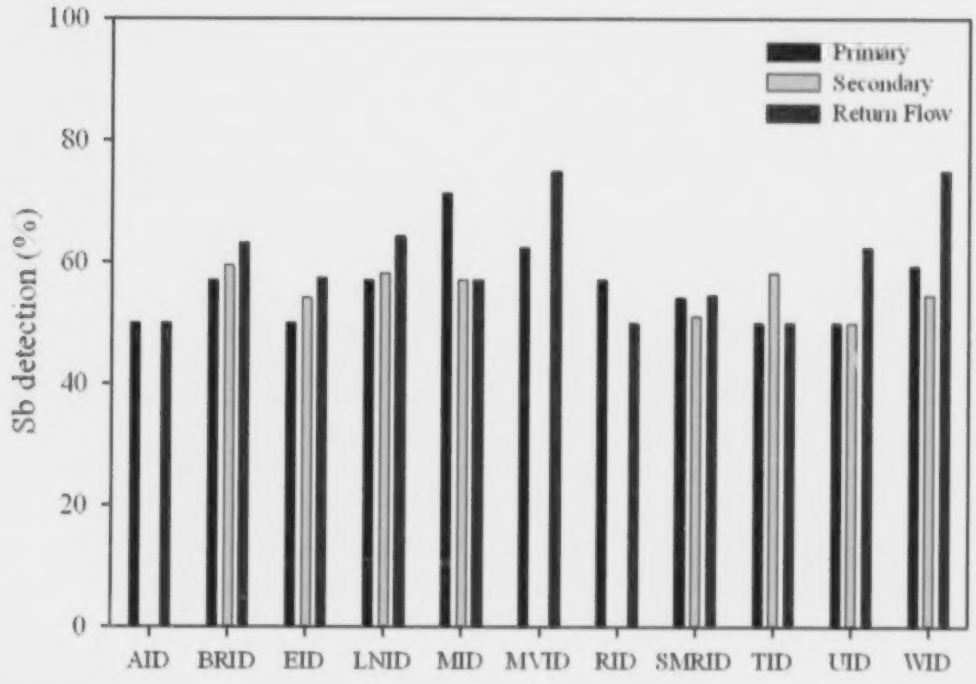

Fig. 36. Antimony (Sb) detection frequencies by irrigation district and site type.

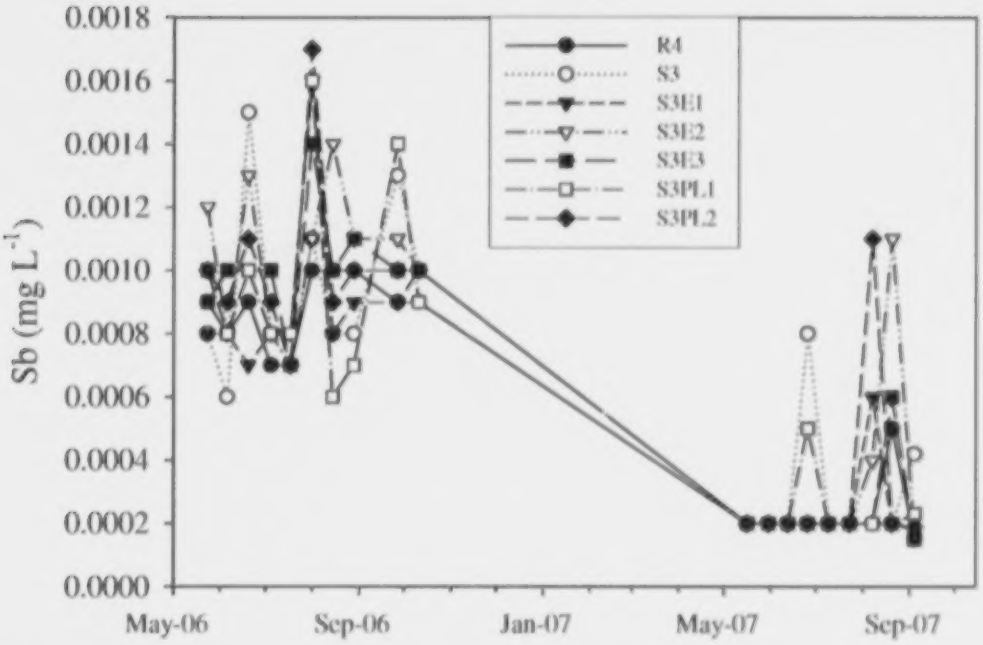

Fig. 37. Antimony (Sb) concentrations at the seven representative sites.

Fig. 38. Percent compliance with CCME arsenic (As) guidelines for the protection of aquatic life (PAL) (0.005 mg L^{-1}, CCME 1999).

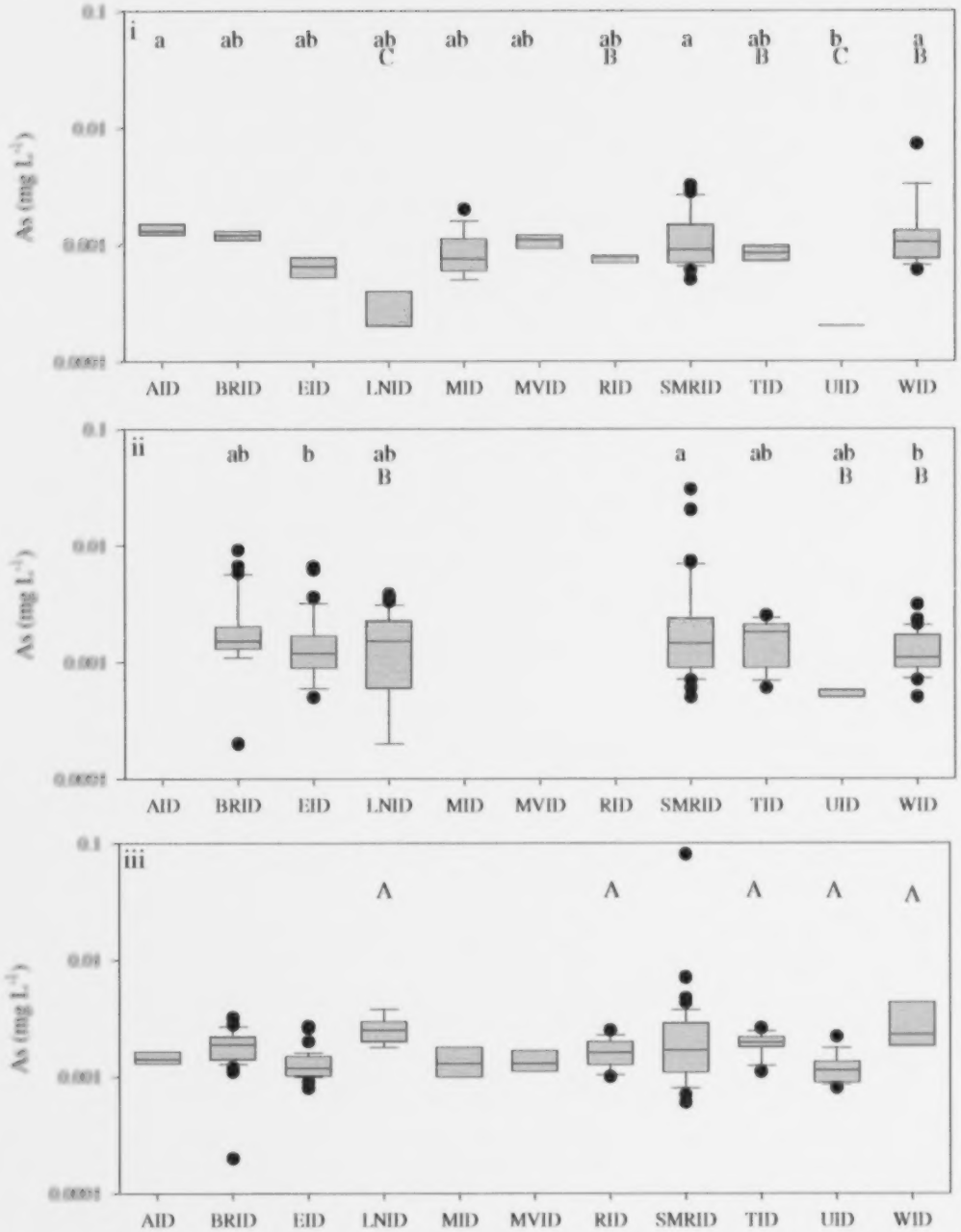

Fig. 39. Boxplots of arsenic (As) concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (within the same graph), while boxes with different uppercase letters are significantly different within each irrigation district (boxes above or below) at $p<0.05$. Note that the y-axis is presented on a log scale.

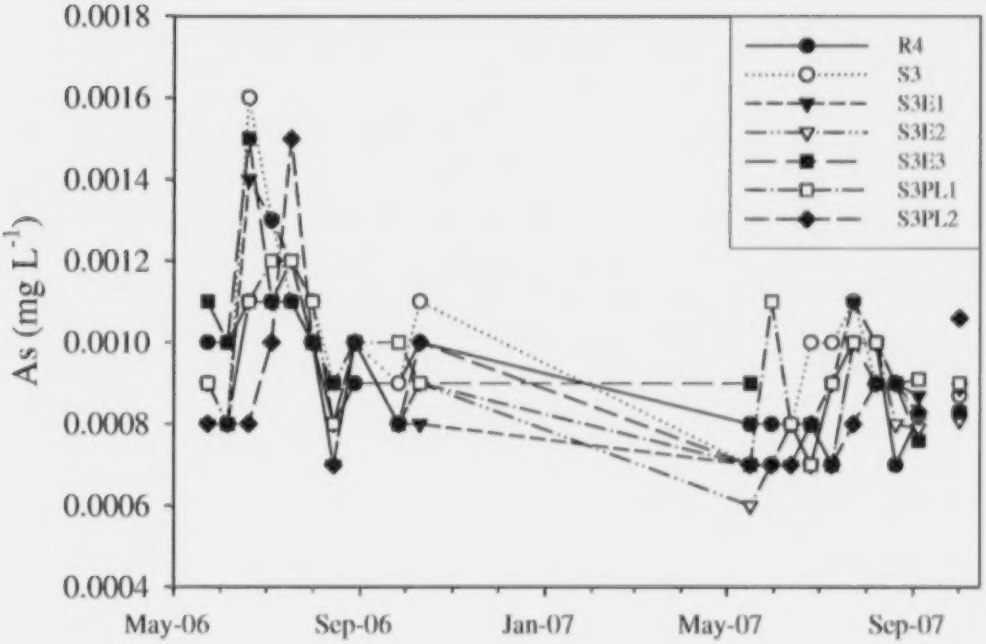

Fig. 40. Arsenic (As) concentrations at the seven representative sites.

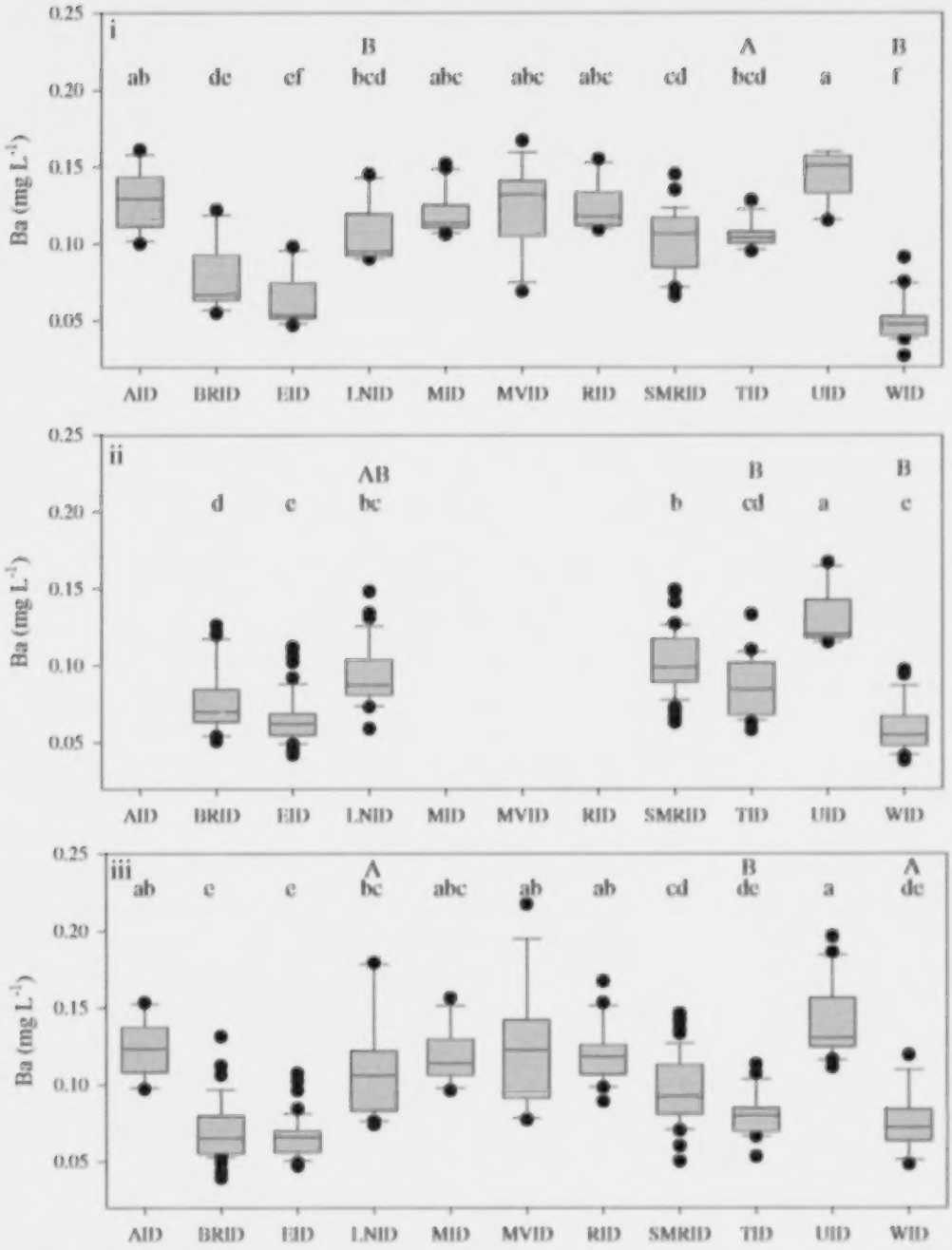

Fig. 41. Boxplots of barium (Ba) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

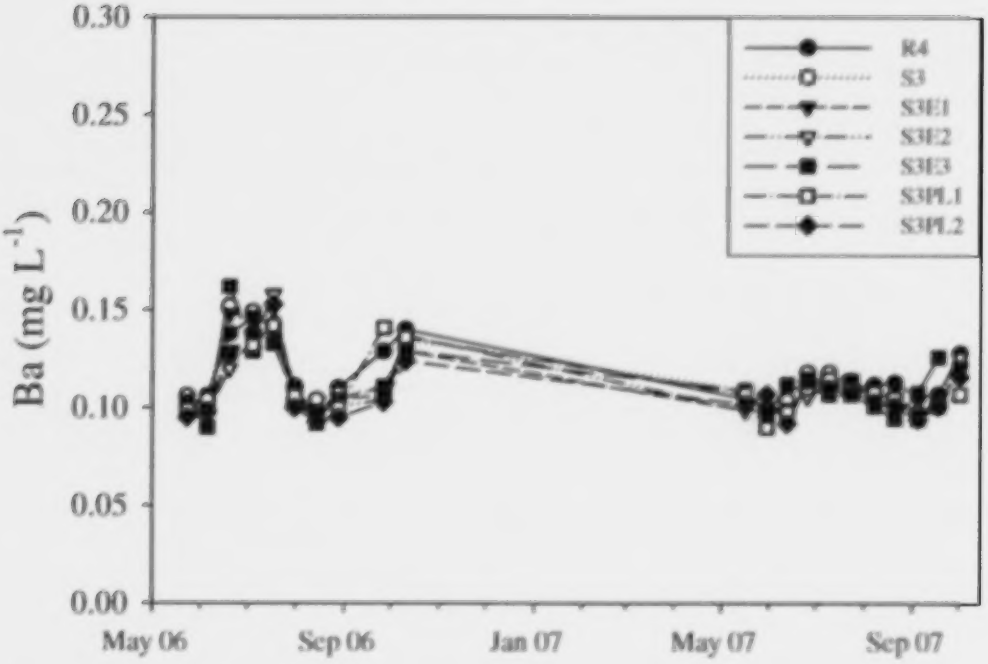

Fig. 42. Barium (Ba) concentrations at the seven representative sites.

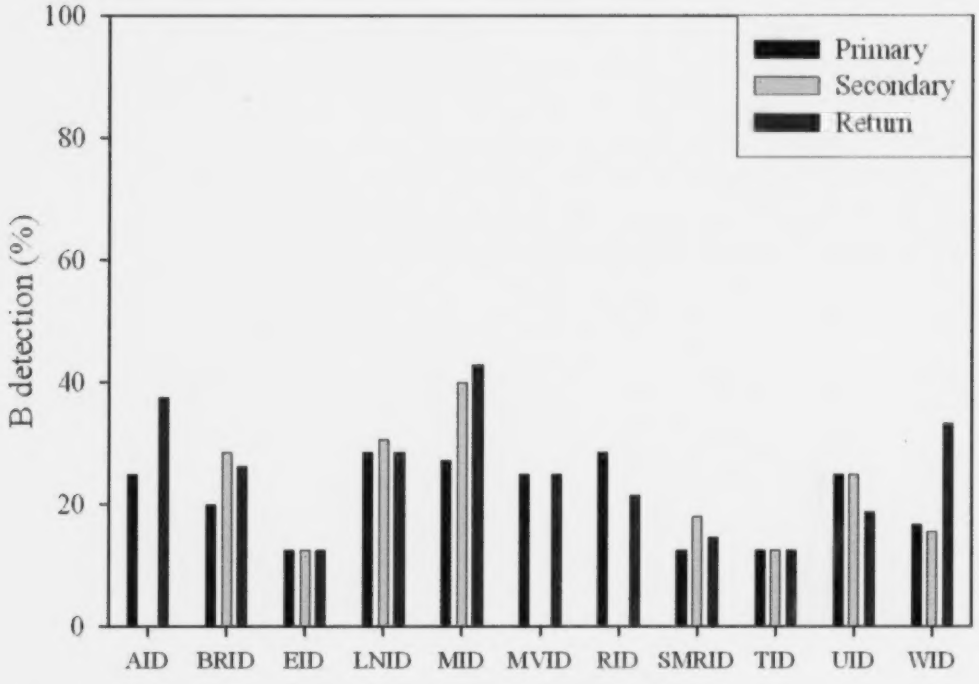

Fig. 43. Detection frequency of boron (B) by irrigation district and site type.

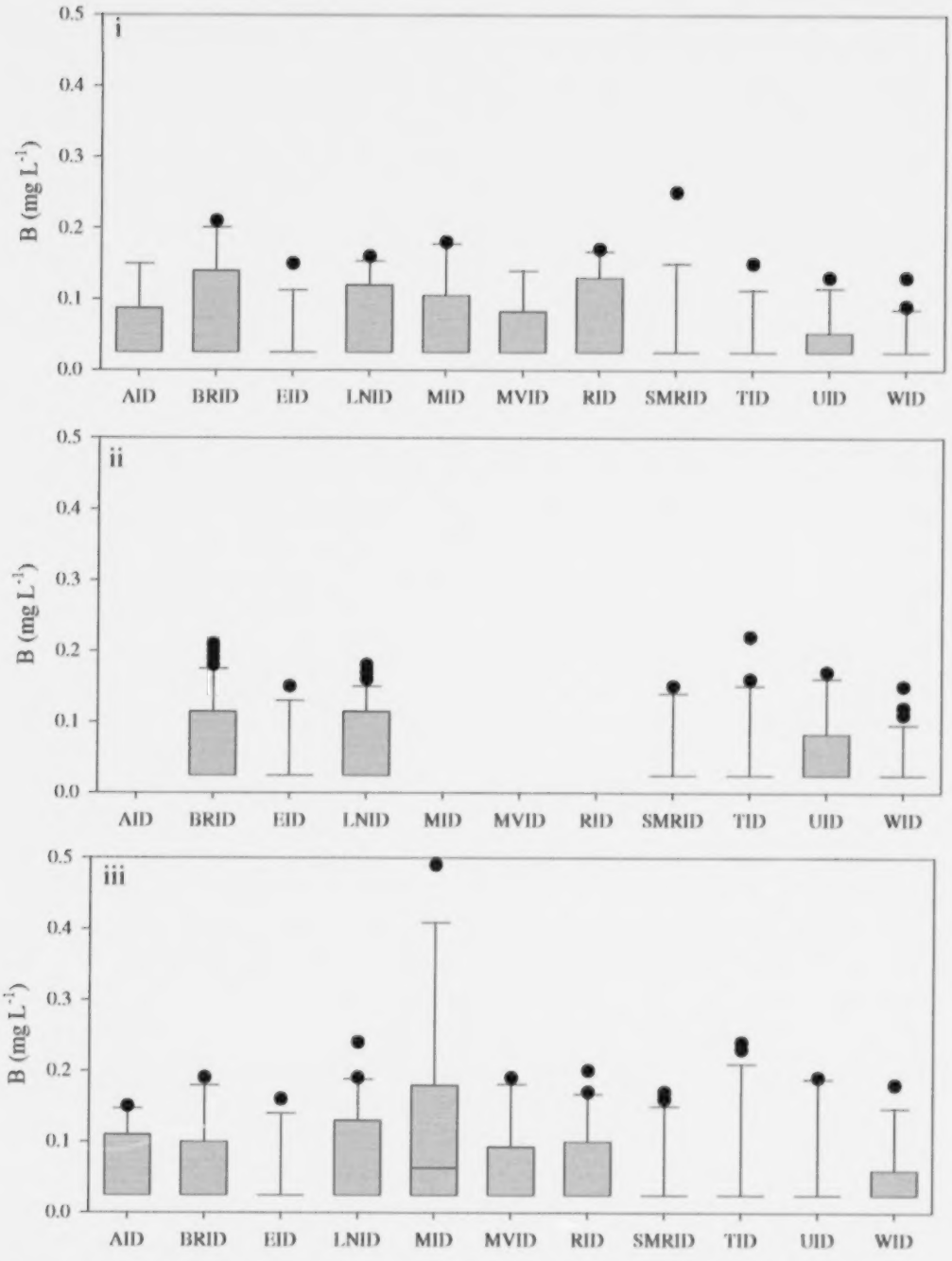

Fig. 44. Boxplots of boron (B) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

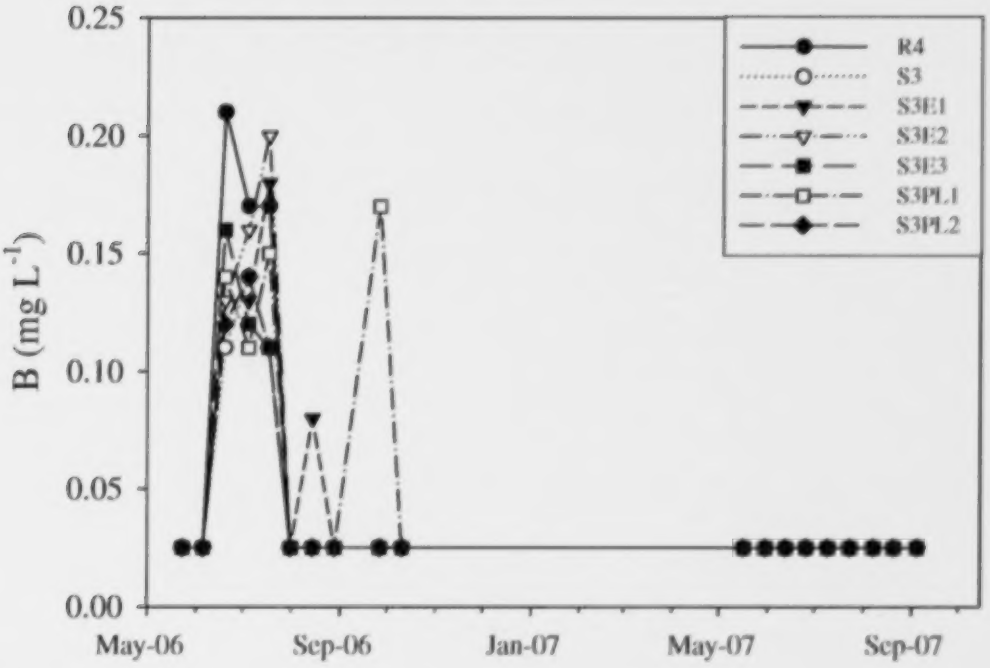

Fig. 45. Boron (B) concentrations at the seven representative sites.

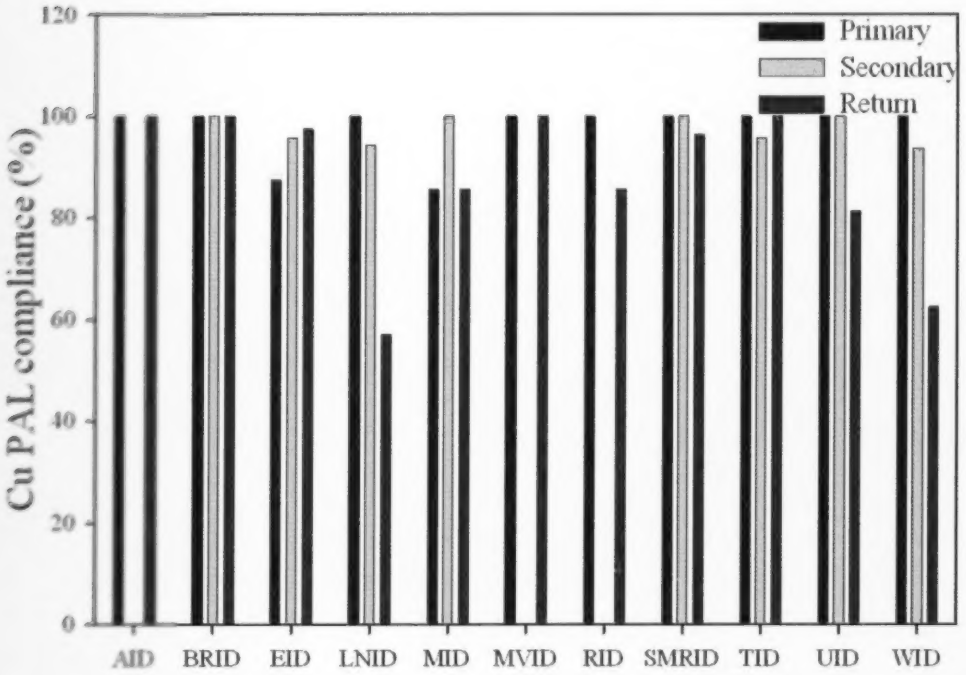

Fig. 46. Percent compliance with CCME copper (Cu) guidelines for the protection of aquatic life (PAL). Guideline values depend on water hardness (CCREM 1987).

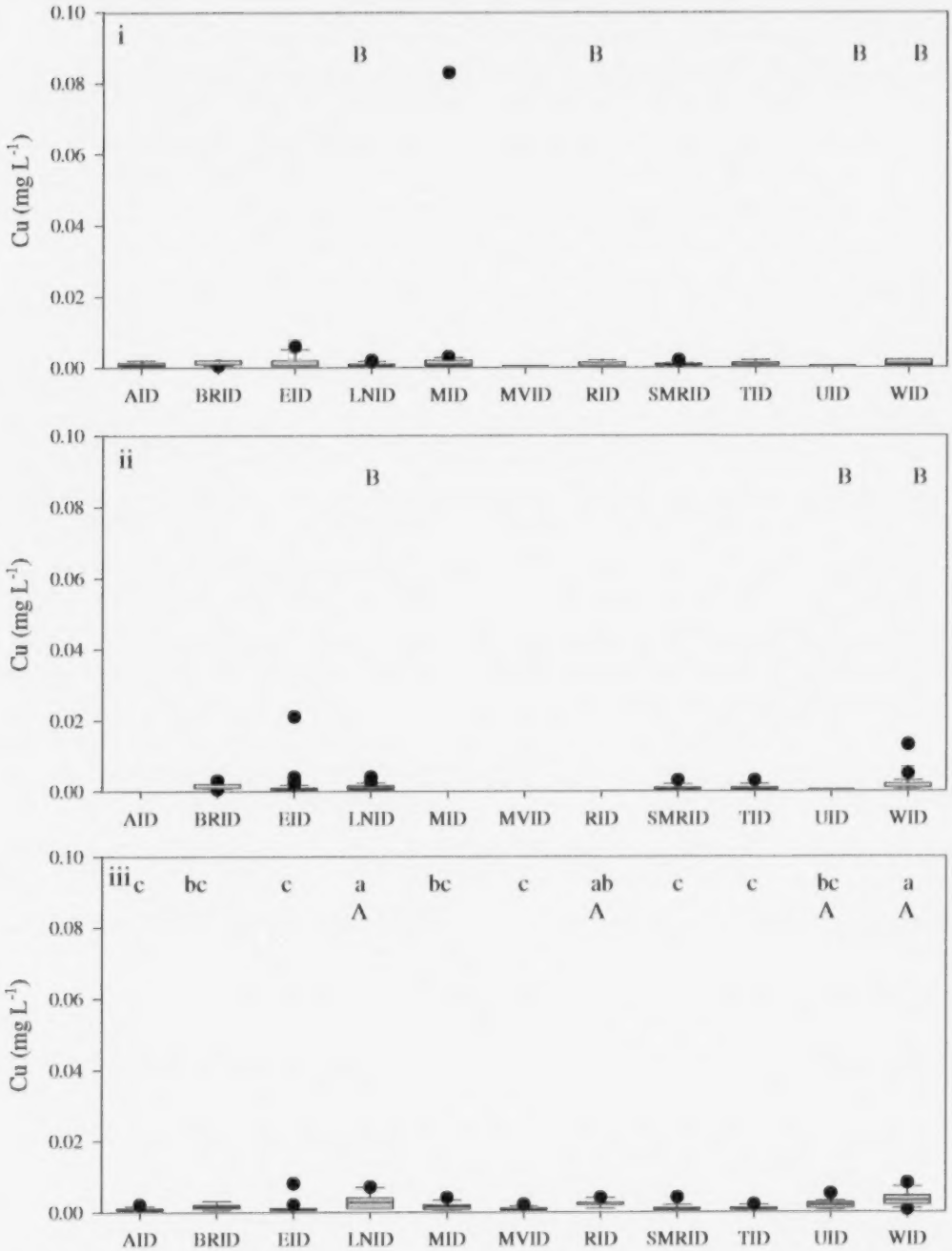

Fig. 47. Boxplots of copper (Cu) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

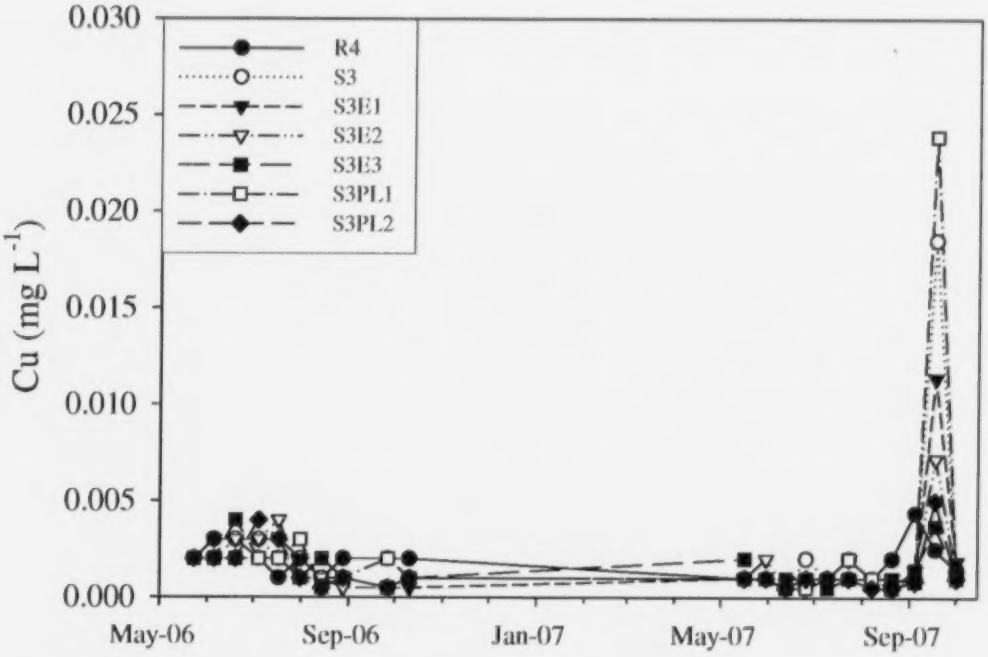

Fig. 48. Copper concentrations at the seven representative sites.

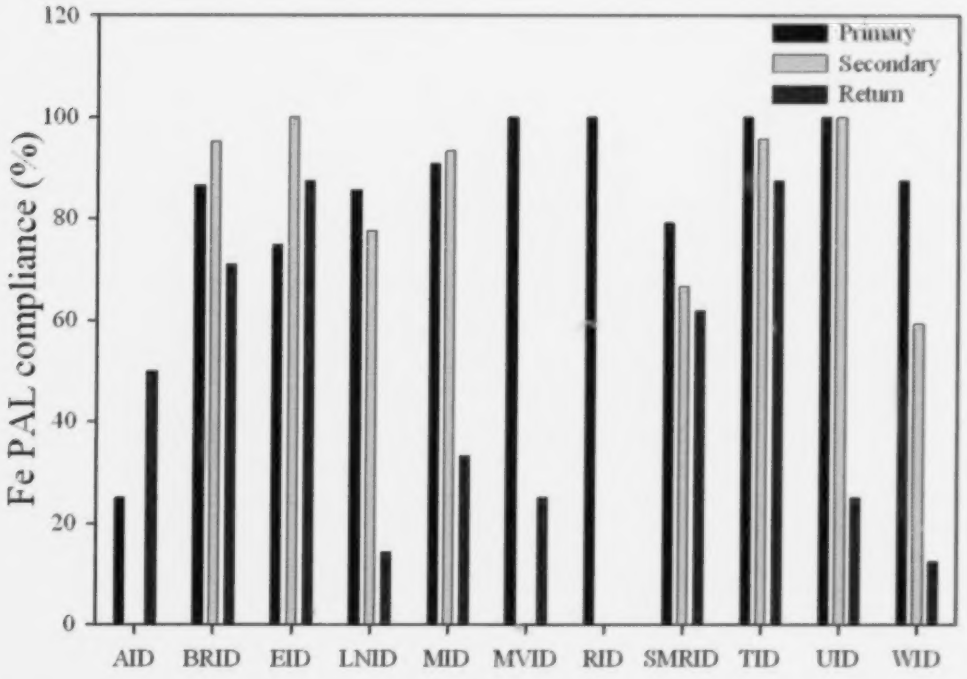

Fig. 49. Percent compliance with CCME guidelines for the protection of aquatic life (PAL) (0.3 mg L^{-1}, CCREM 1987) for iron (Fe) by irrigation district and site type.

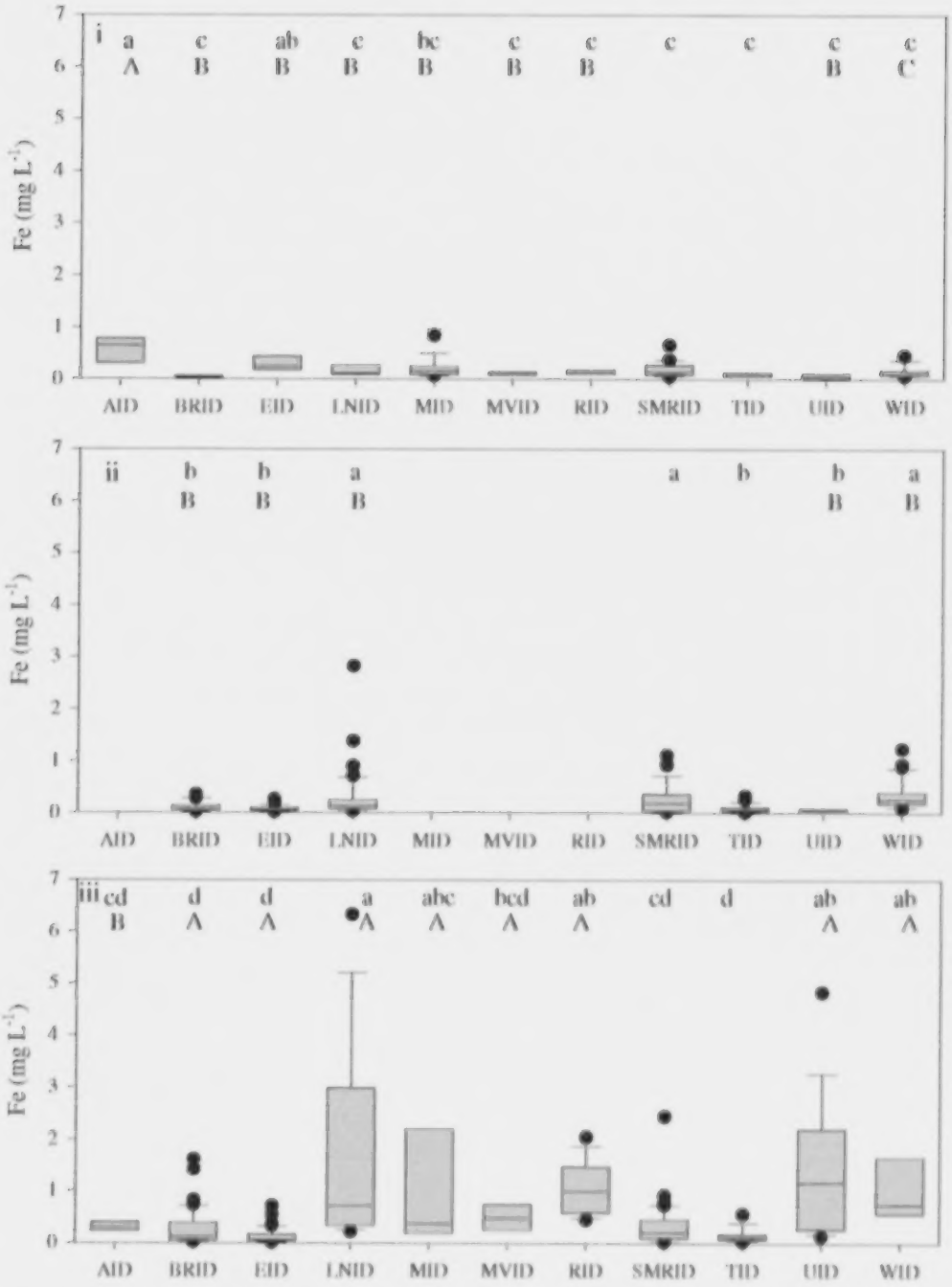
i
a c ab c bc c c c c c c
A B B B B B B B
ii
b b a a b b a
B B B B B
iii
cd d d a abc bcd ab cd d ab ab
B A A A A A A A
Fe (mg L-1)
0 1 2 3 4 5 6 7
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 50. Boxplots of iron (Fe) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (within the same graph), while boxes with different uppercase letters are significantly different within each irrigation district (boxes above or below) at $p<0.05$.

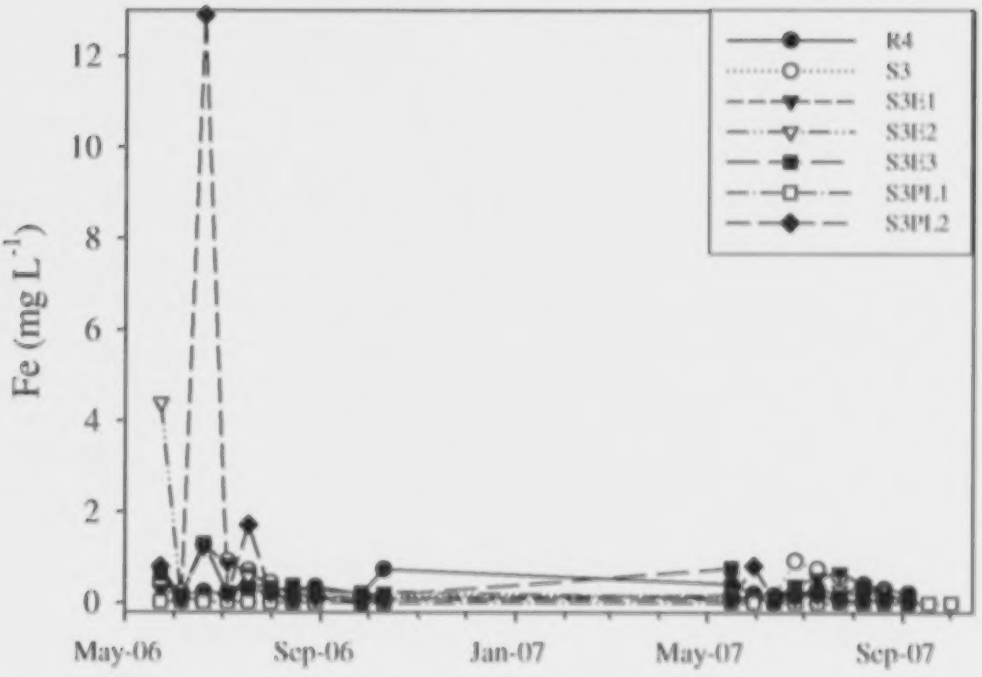

Fig. 51. Iron (Fe) concentrations at the seven representative sites.

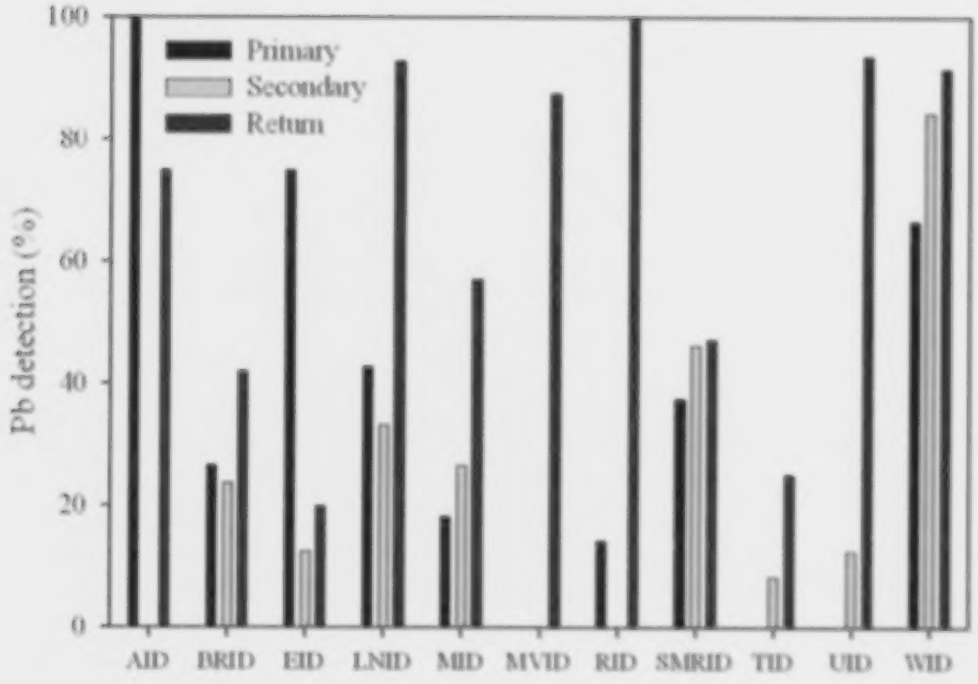

Fig. 52. Detection frequency of lead (Pb) by irrigation district and site type.

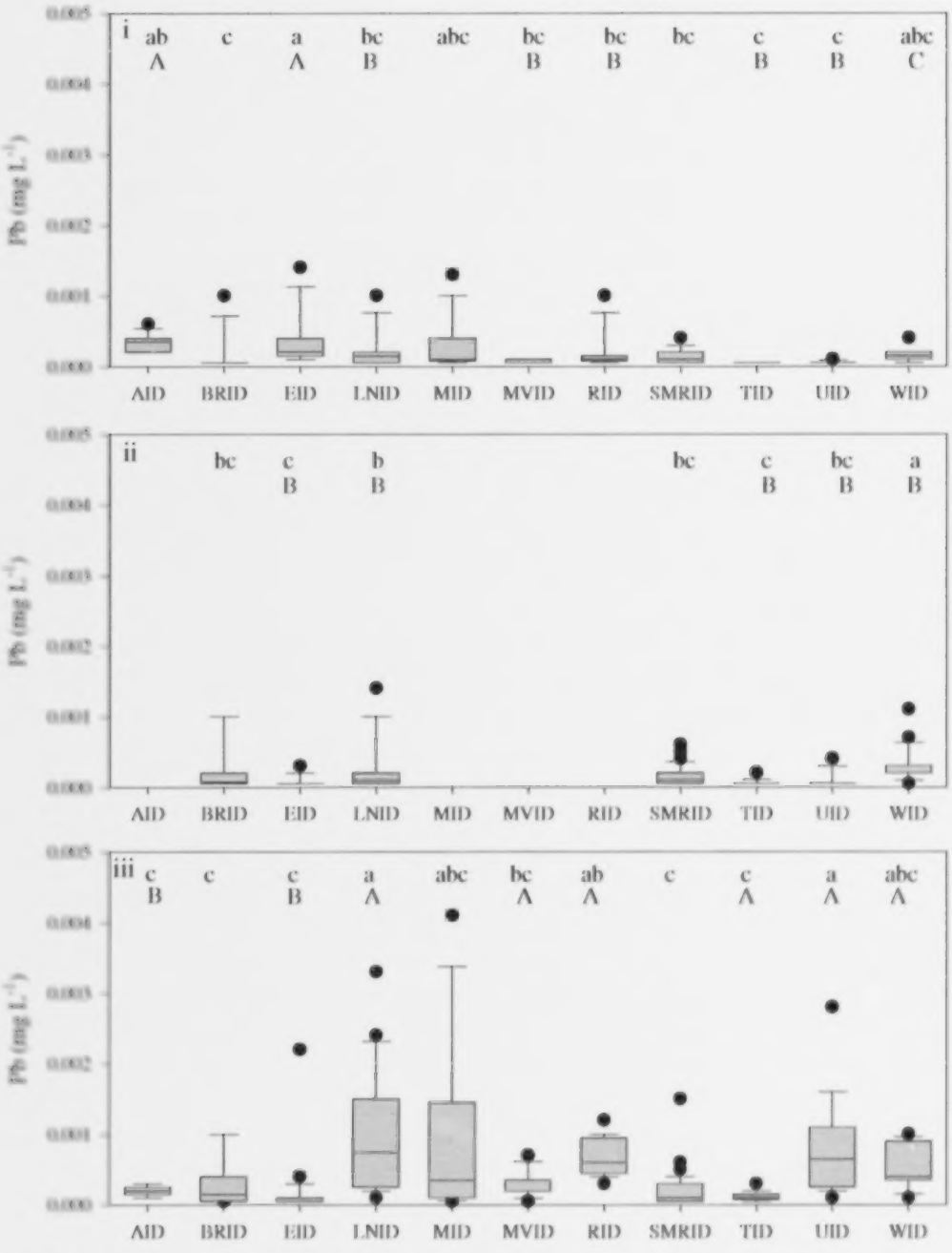

Fig. 53. Boxplots of lead (Pb) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

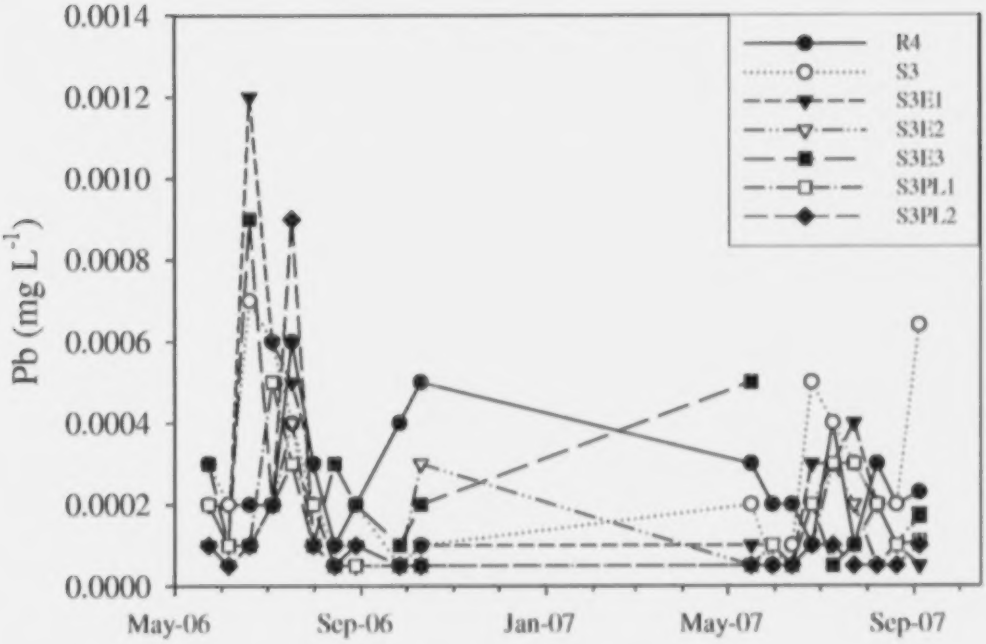

Fig. 54. Lead (Pb) concentrations at the seven representative sites.

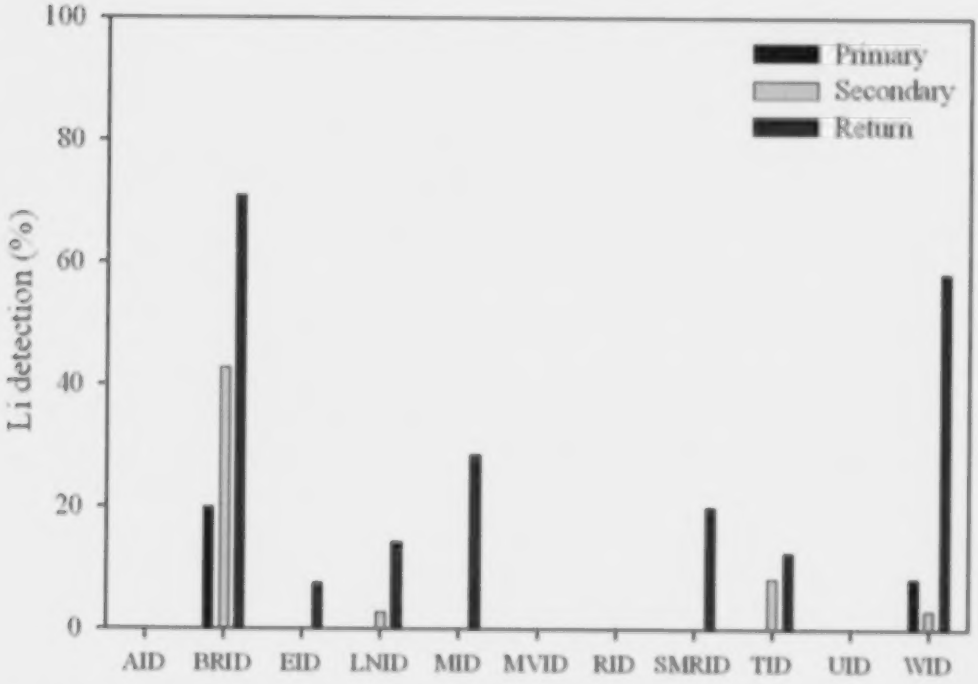

Fig. 55. Detection frequencies of lithium (Li) by irrigation district and site type.

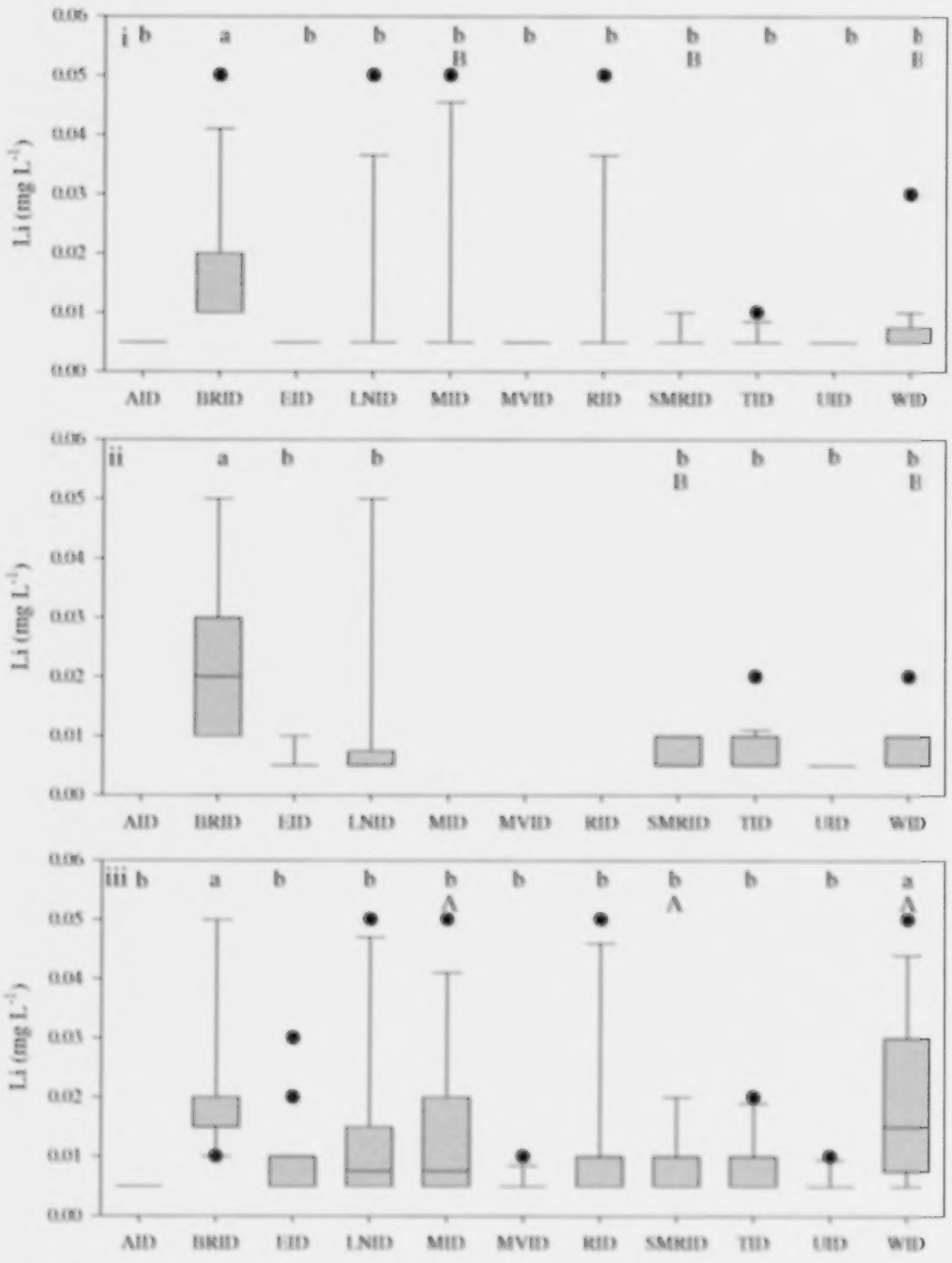

Fig. 56. Boxplots of lithium concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

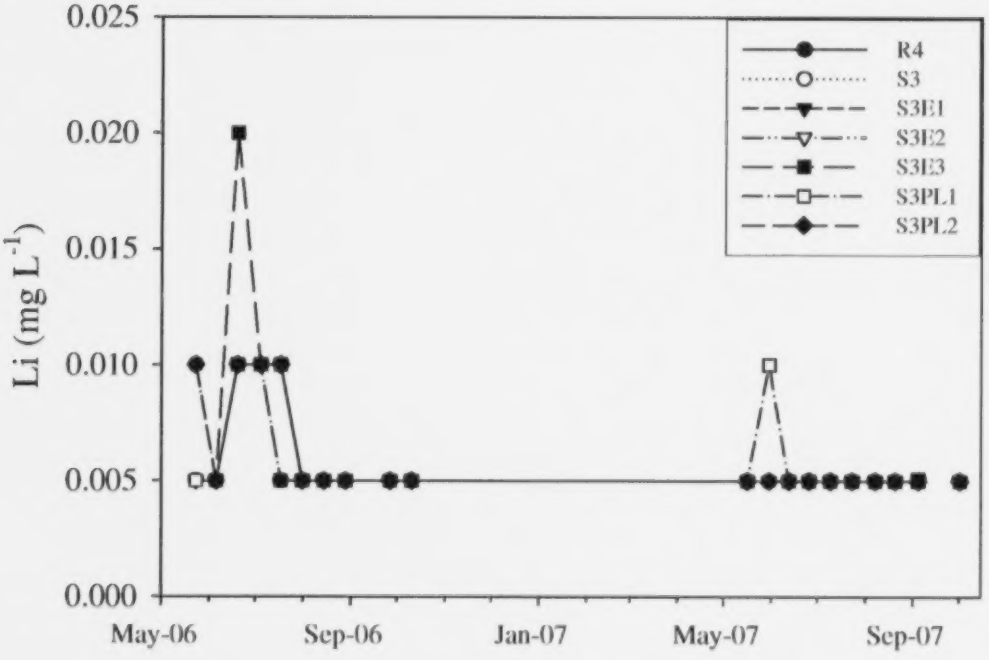

Fig. 57. Lithium (Li) concentrations at the seven representative sites.

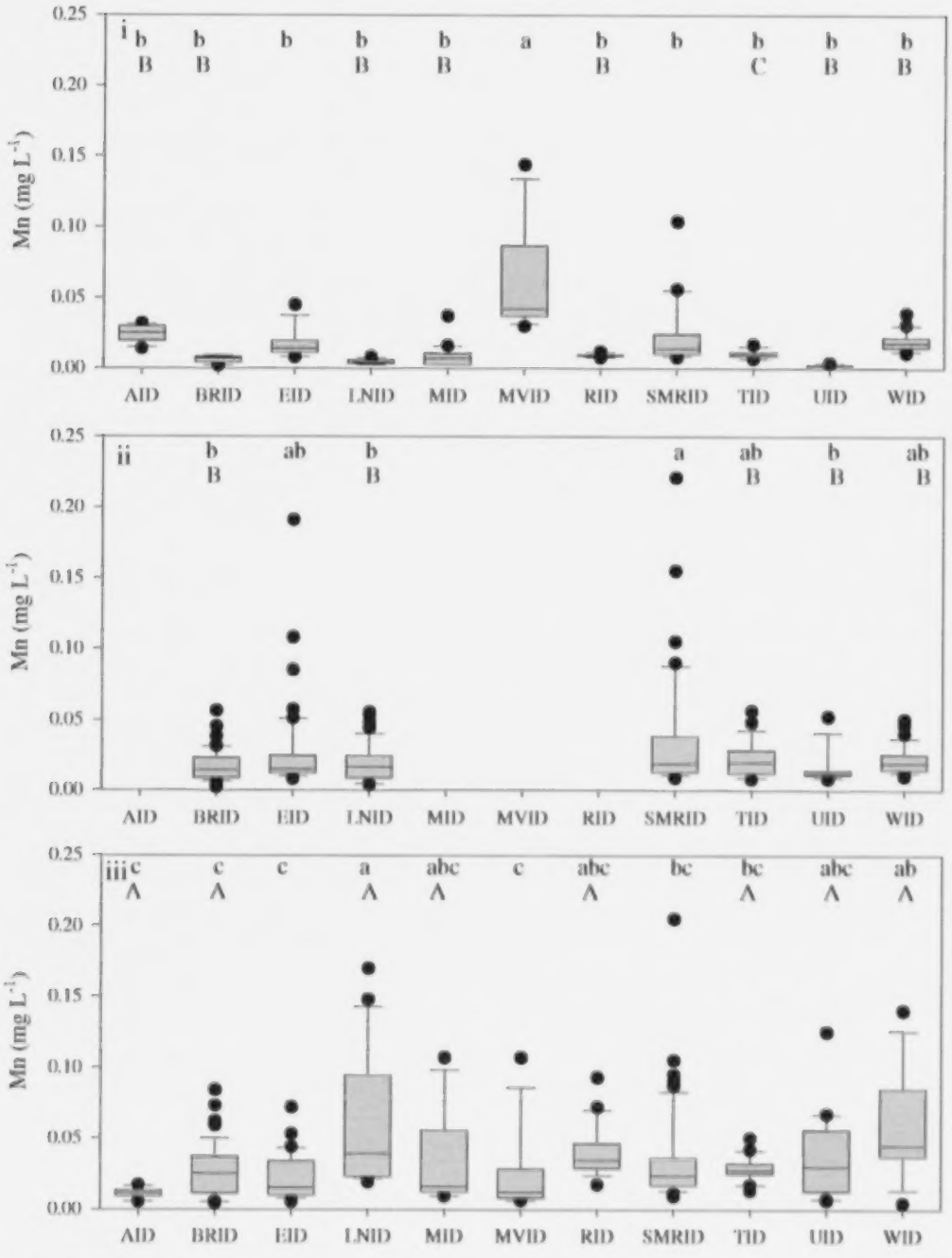
i
ii
iii
Mn (mg L-1)
0.25
0.20
0.15
0.10
0.05
0.00
b b b b b a b b b b b
B B B B B C B B
b ab b a ab b ab
B B B B B
c c c a abc c abc bc bc abc ab
A A A A A A A A
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 58. Boxplots of manganese (Mn) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

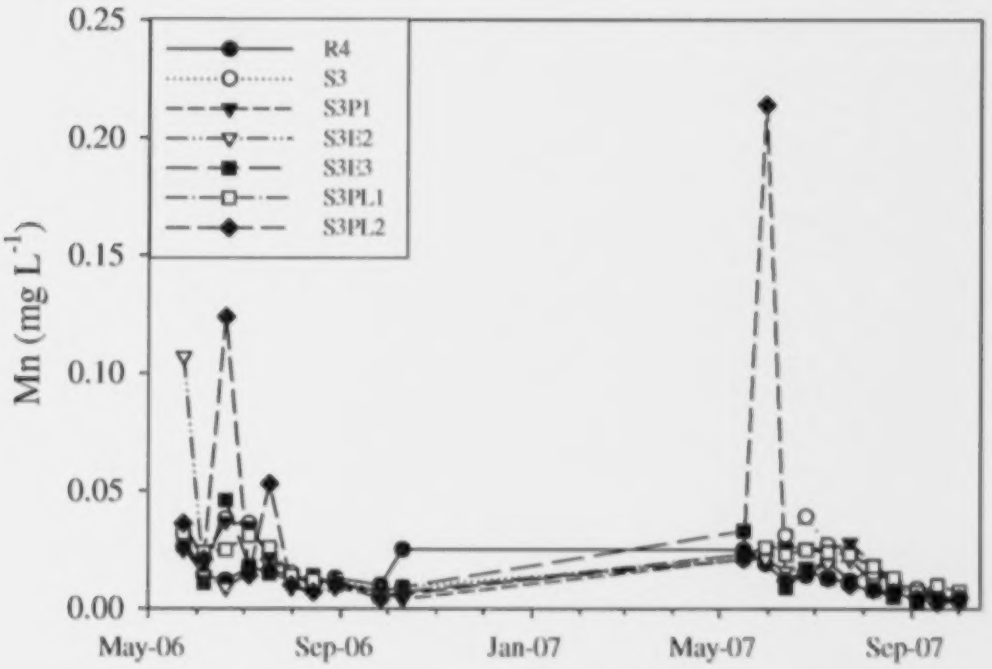

Fig. 59. Manganese (Mn) concentrations at the seven representative sites.

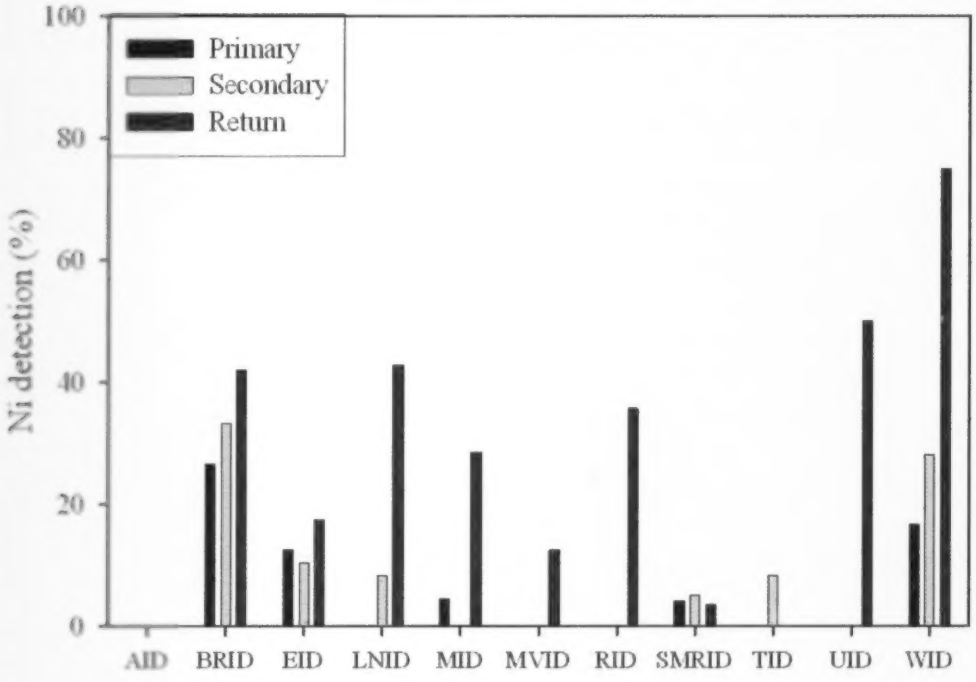

Fig. 60. Detection frequencies of nickel (Ni) by irrigation district and site type.

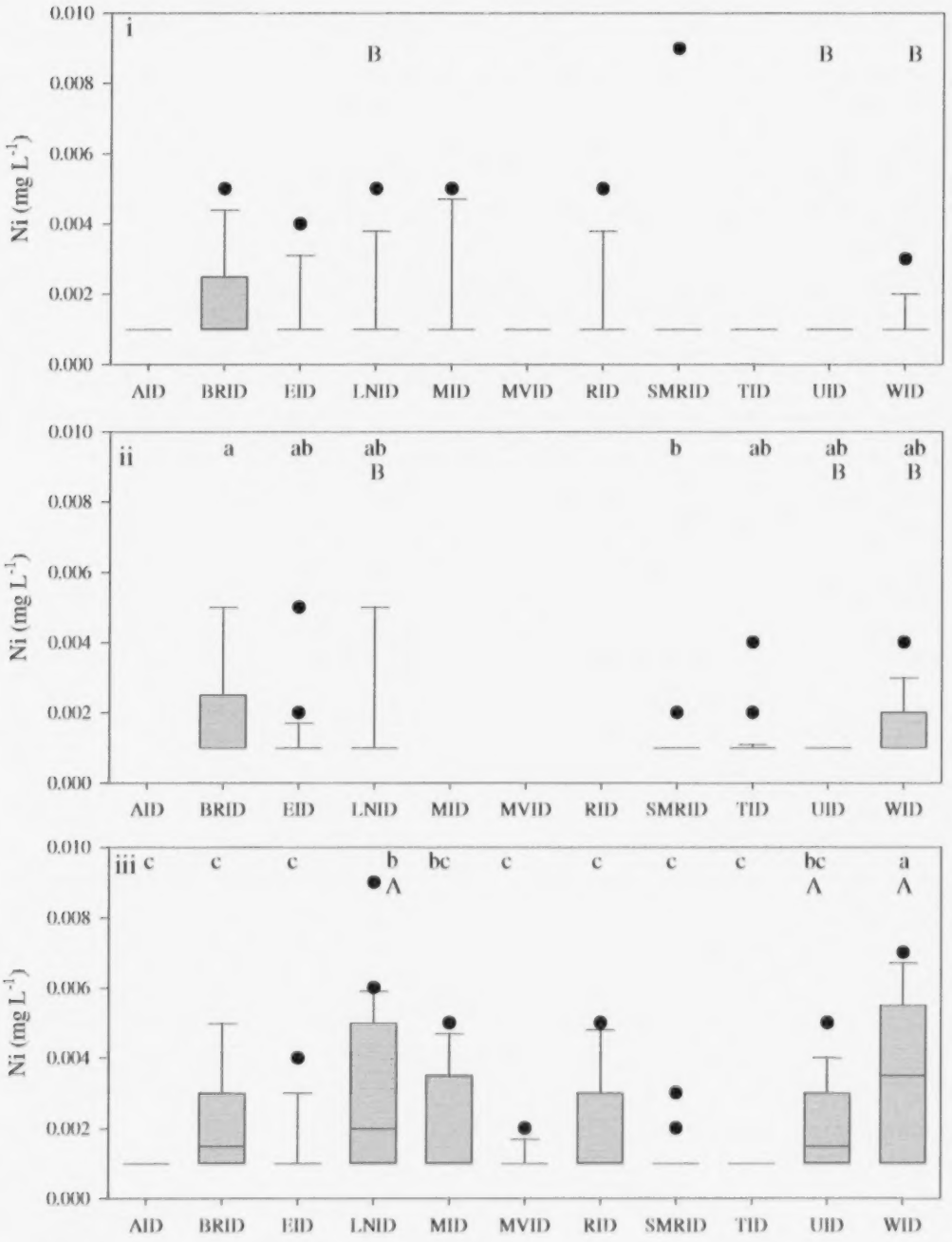

Fig. 61. Boxplots of nickel (Ni) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

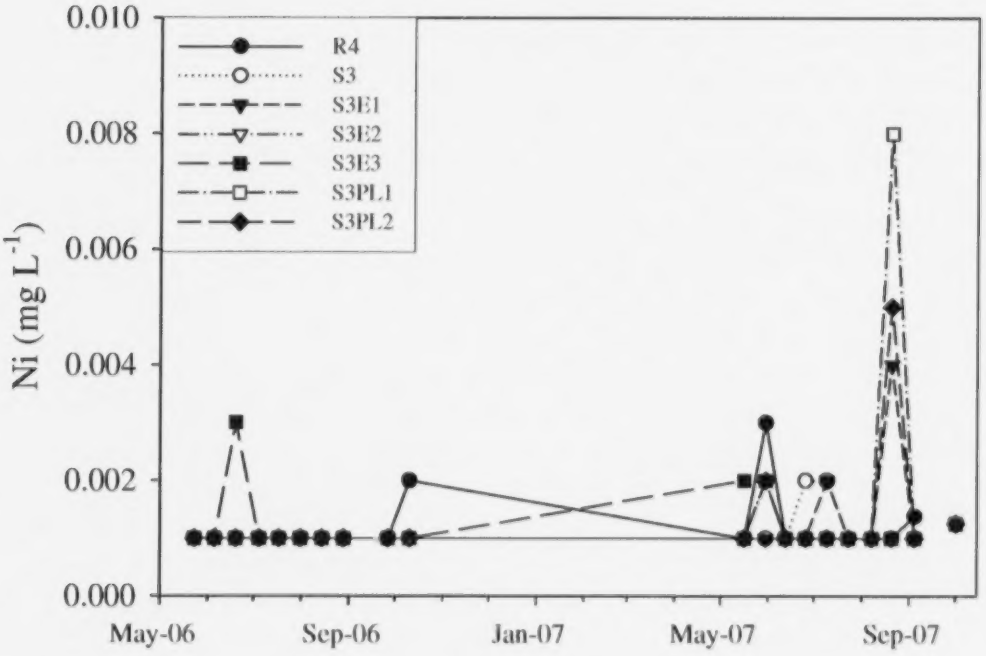

Fig. 62. Nickel (Ni) concentrations at the seven representative sites.

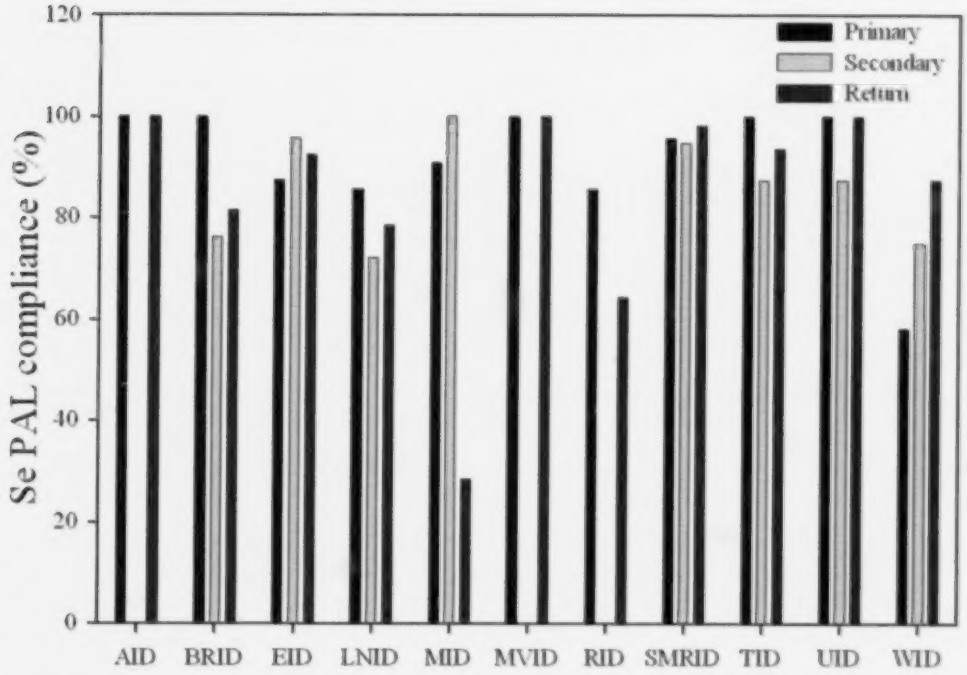

Fig. 63. Percent compliance CCME selenium (Se) guidelines for the protection of aquatic life (PAL) (0.001 mg L^{-1}, CCREM 1987).

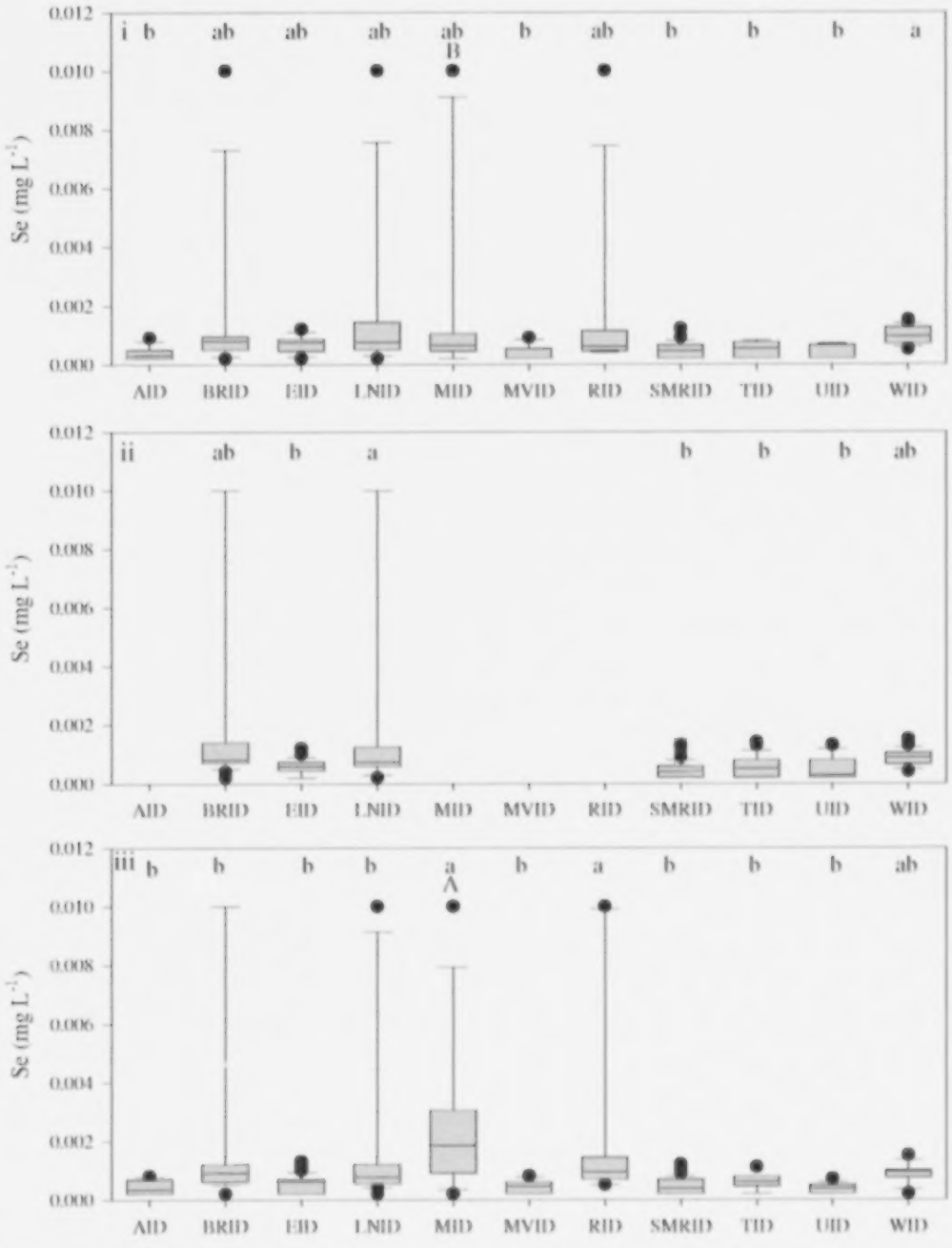

Fig. 64. Boxplots of selenium (Se) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (within the same graph), while boxes with different uppercase letters are significantly different within each irrigation district (boxes above or below) at $p<0.05$.

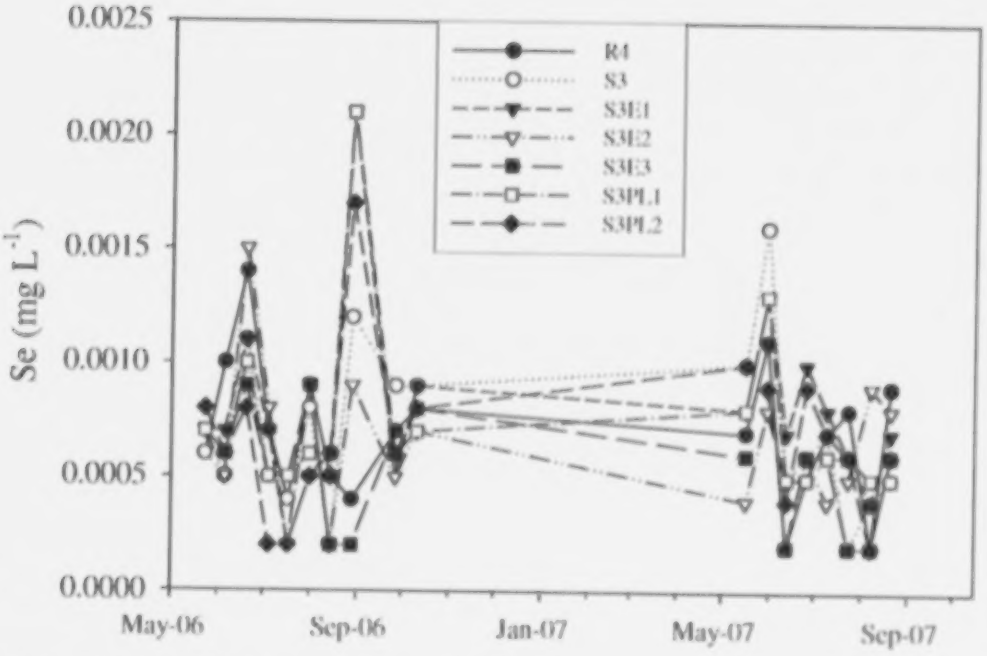

Fig. 65. Selenium (Se) concentrations at the seven representative sites.

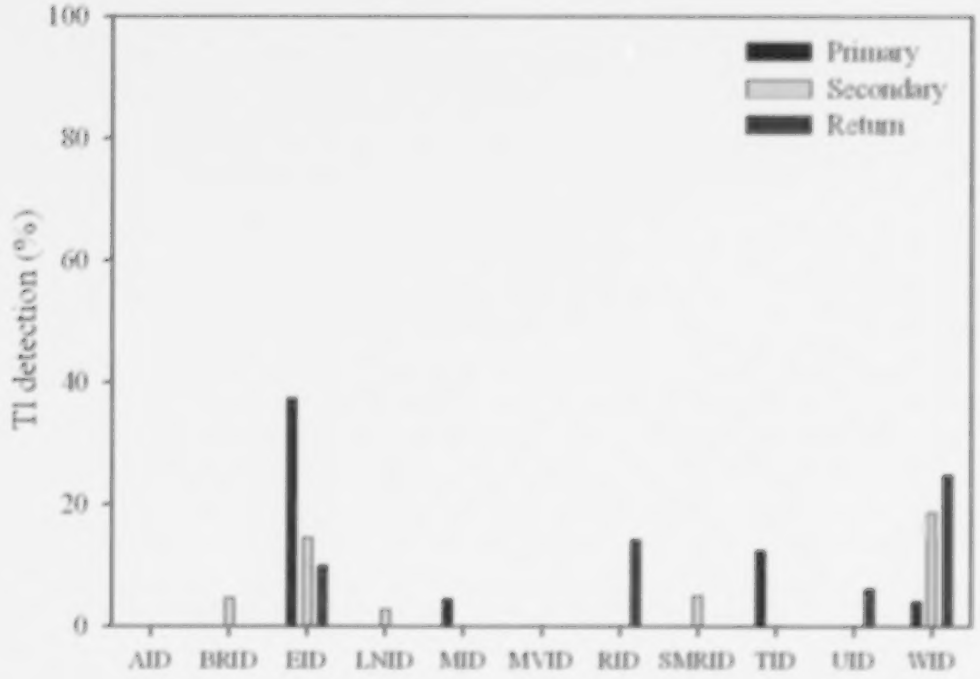

Fig. 66. Detection frequencies of thallium (Tl) by irrigation district and site type.

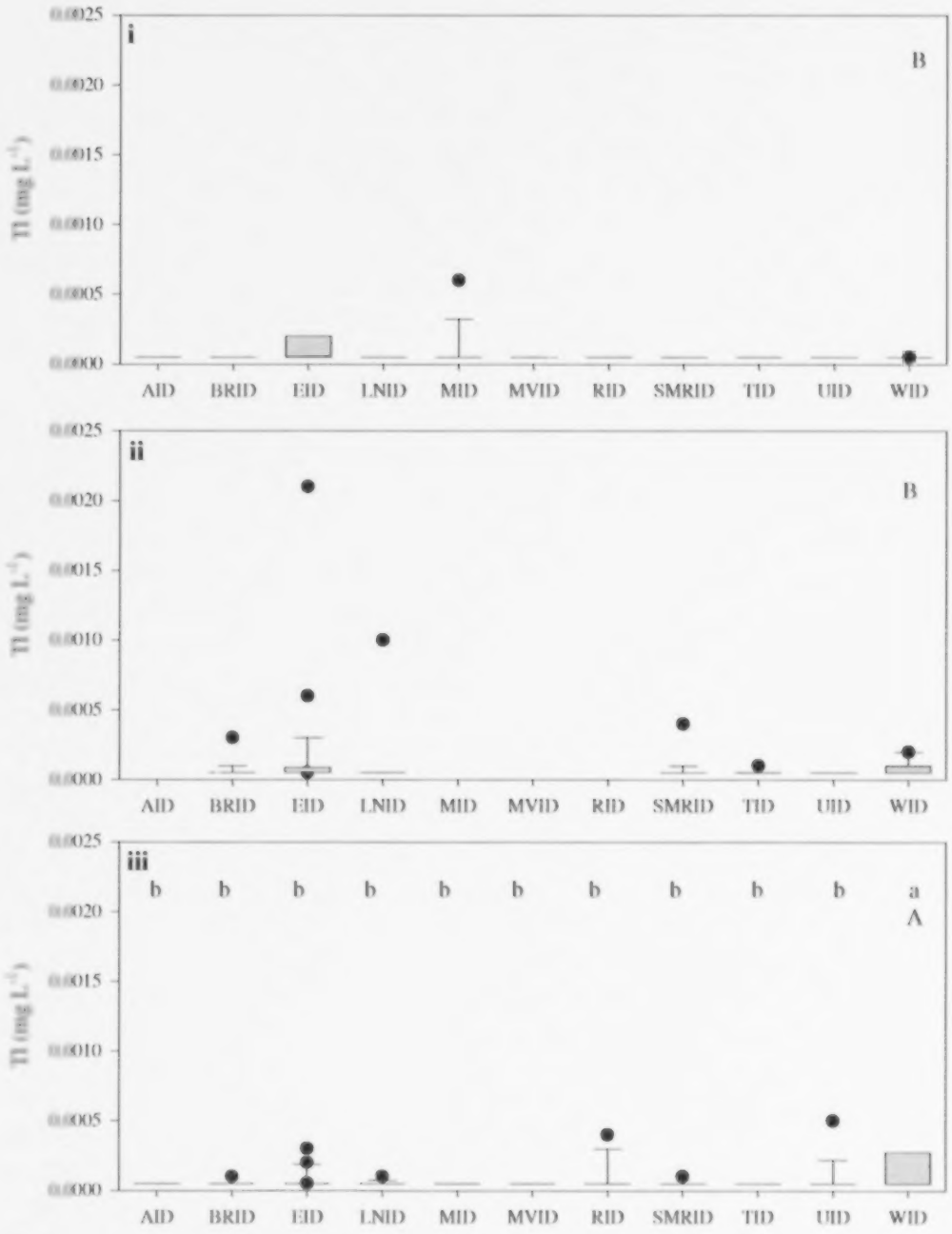

Fig. 67. Boxplots of thallium (Tl) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

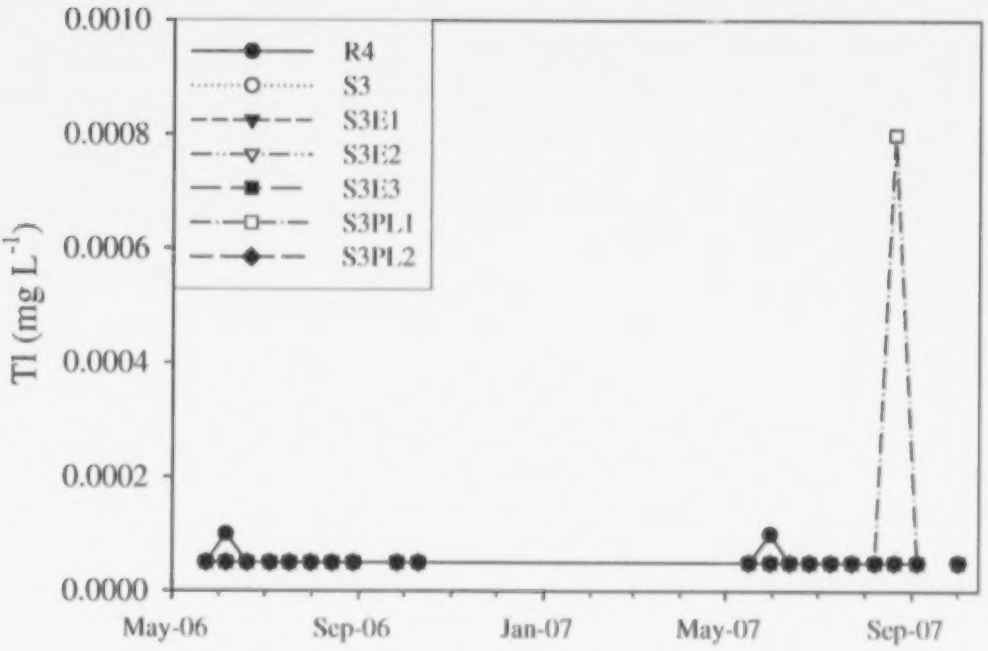

Fig. 68. Thallium (Tl) concentrations at the seven representative sites.

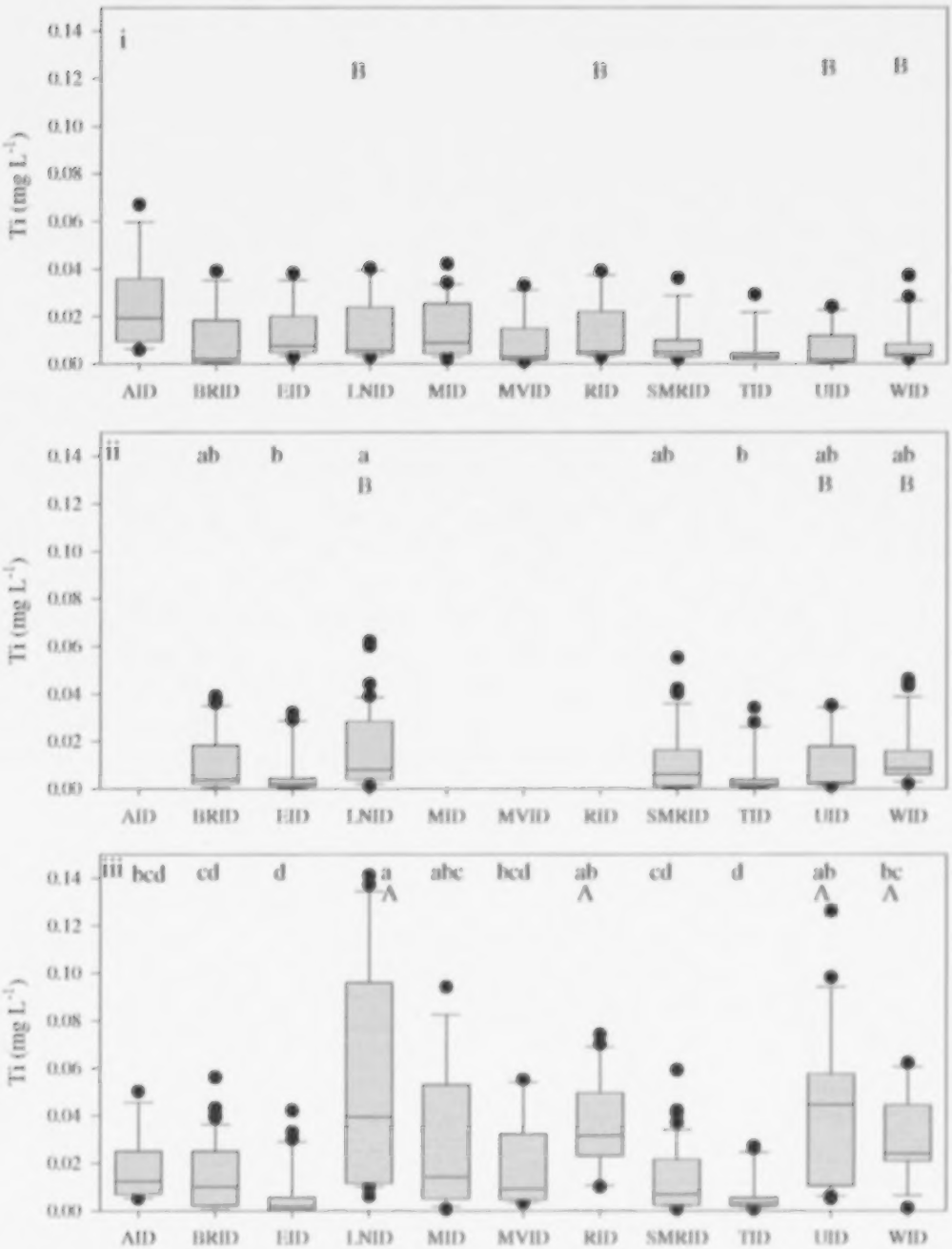

Fig. 69. Boxplots of titanium (Ti) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

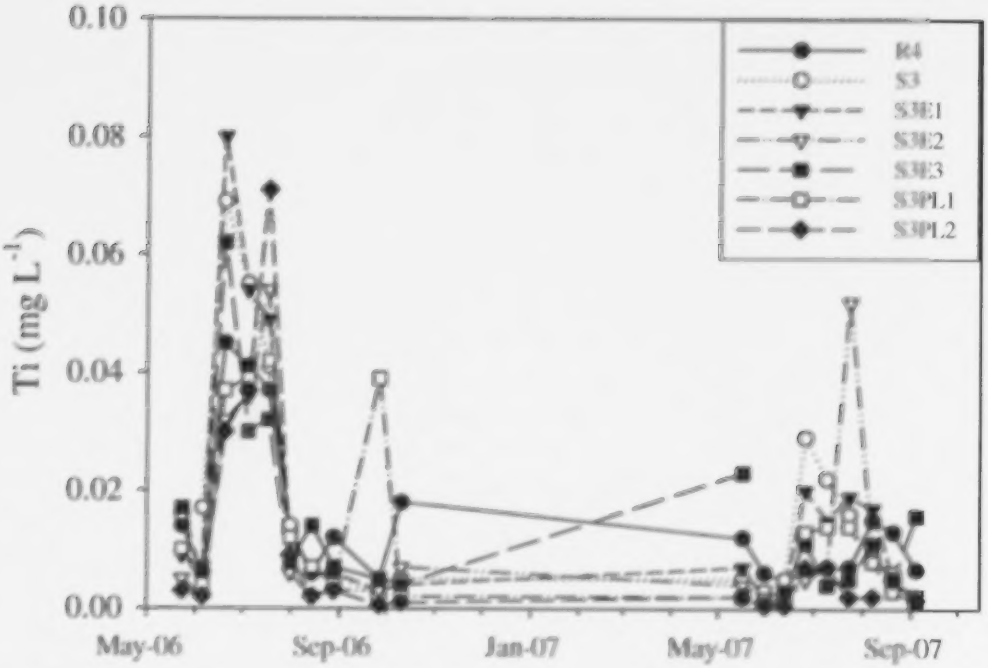

Fig. 70. Titanium (Ti) concentrations at the seven representative sites.

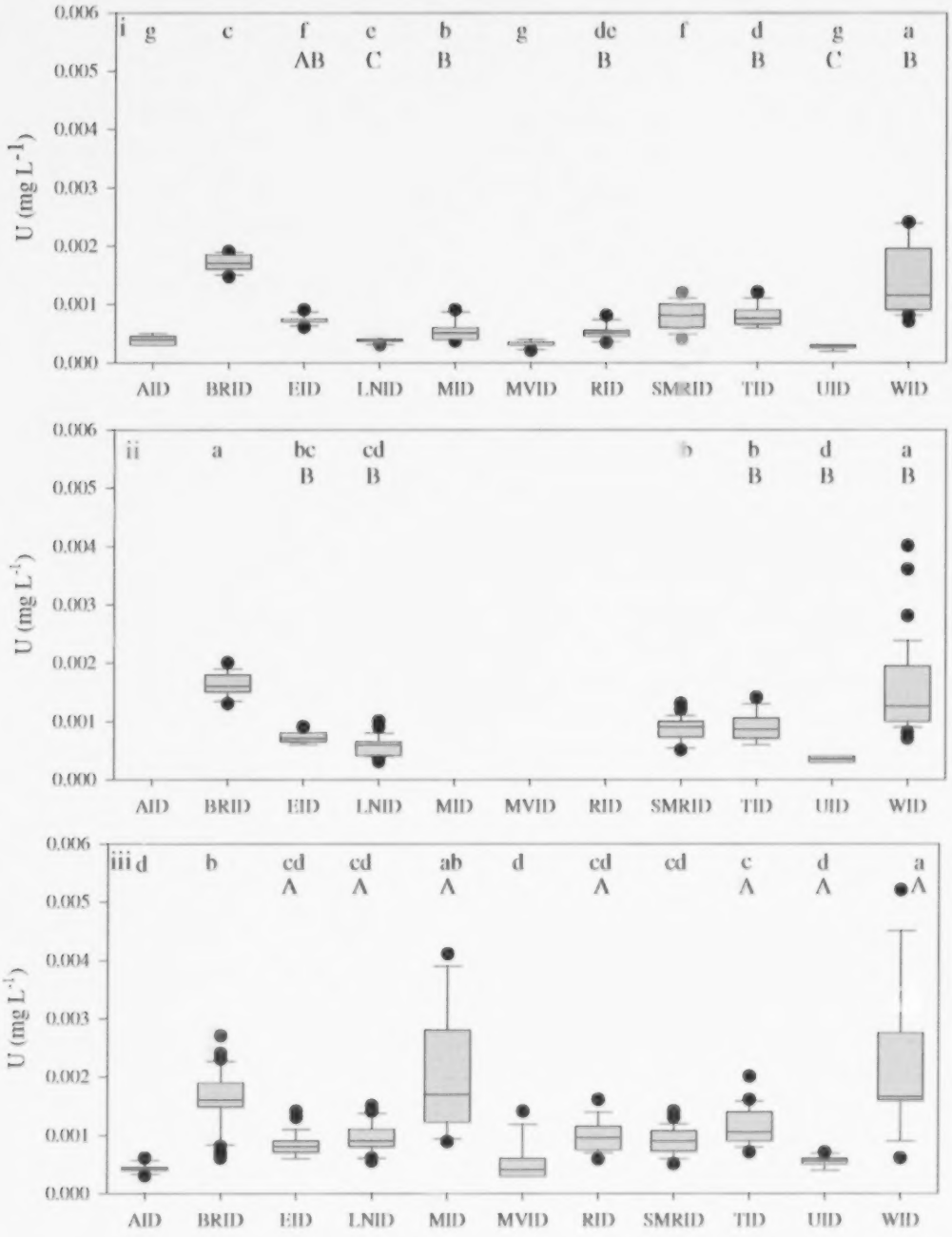

Fig. 71. Boxplots of uranium (U) concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

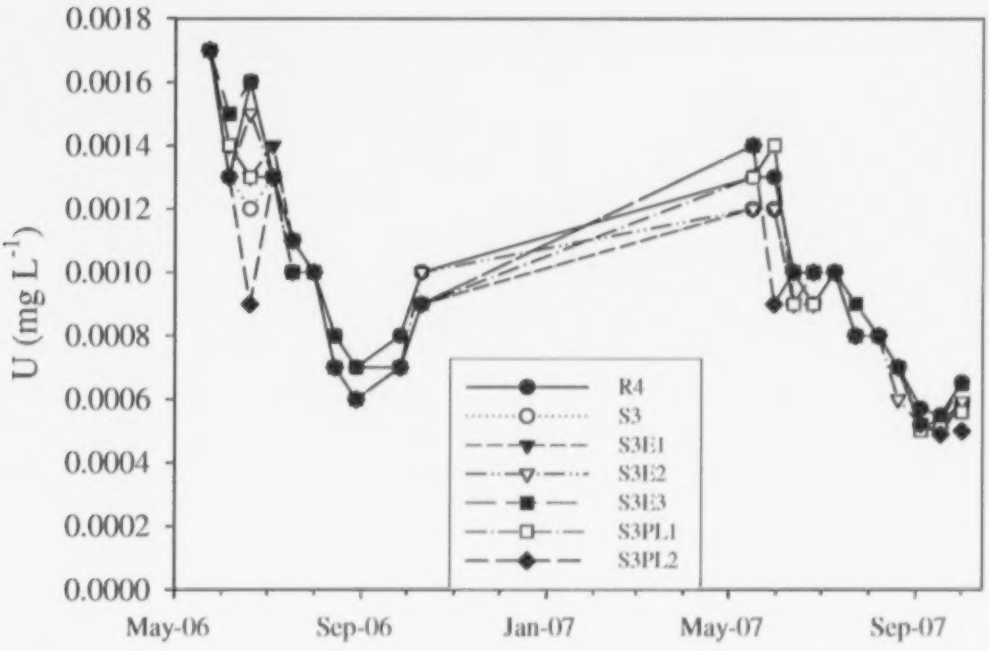

Fig. 72. Uranium (U) concentrations at the seven representative sites.

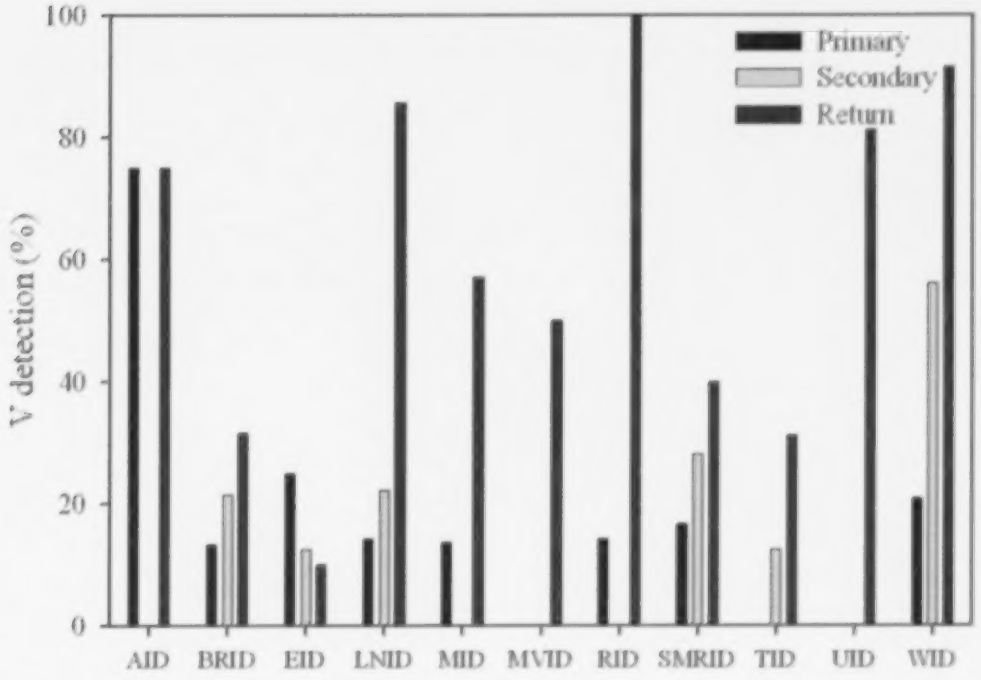

Fig. 73. Detection frequencies of vanadium (V) by irrigation district and site type.

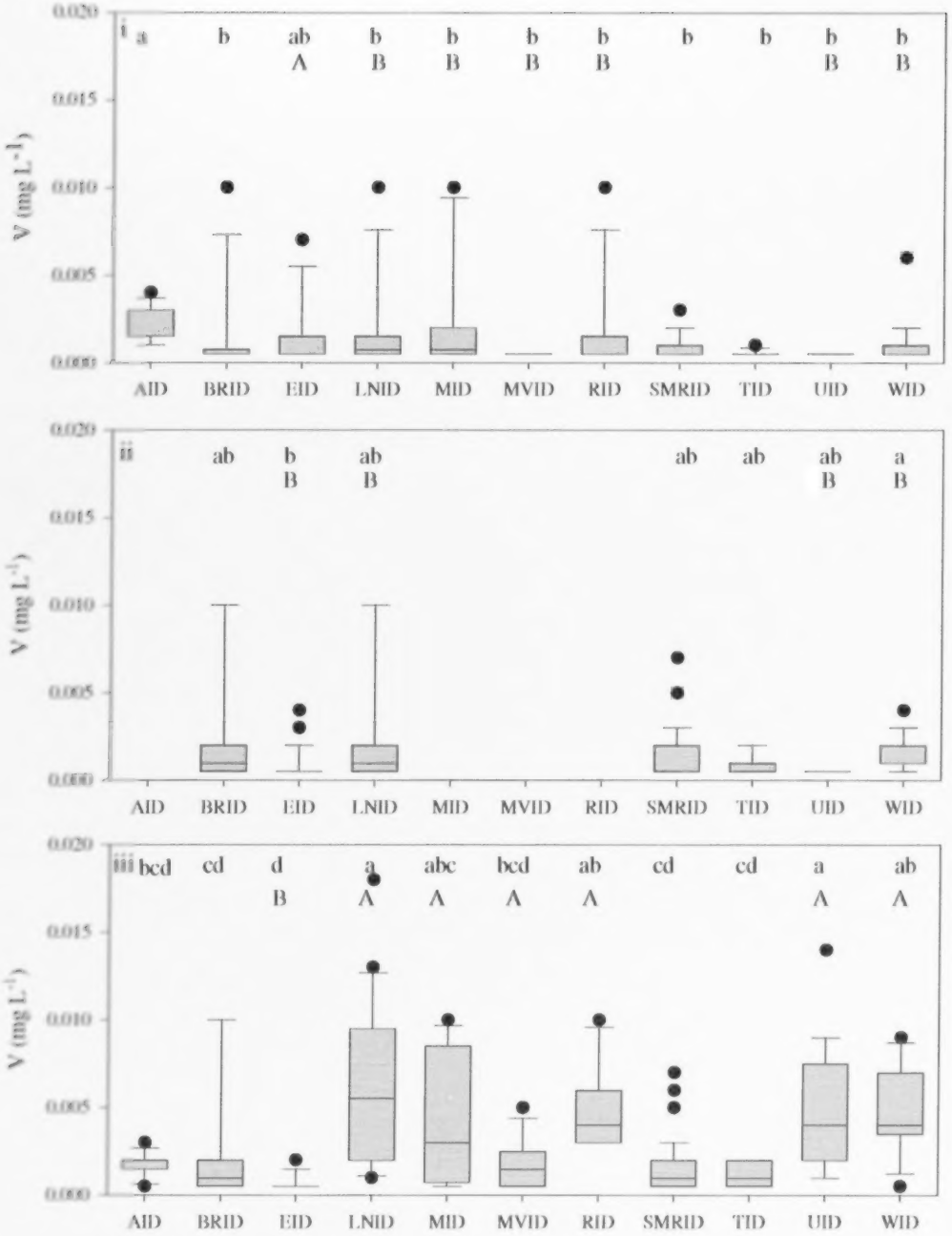
i
ii
iii
V (mg L-1)
0.020
0.015
0.010
0.005
0.000
a b ab b b b b b b b b
A B B B B
ab b ab ab ab a
B B B B
bcd cd d a abc bcd ab cd cd a ab
B A A A A A A
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 74. Boxplots of vanadium (V) concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

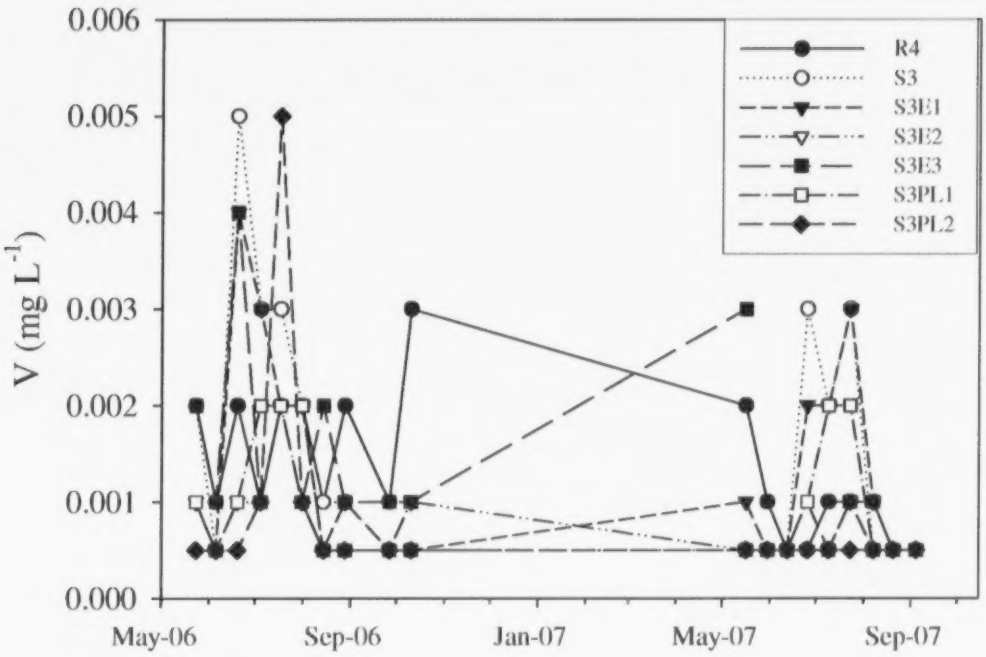

Fig. 75. Vanadium (V) concentrations at the seven representative sites.

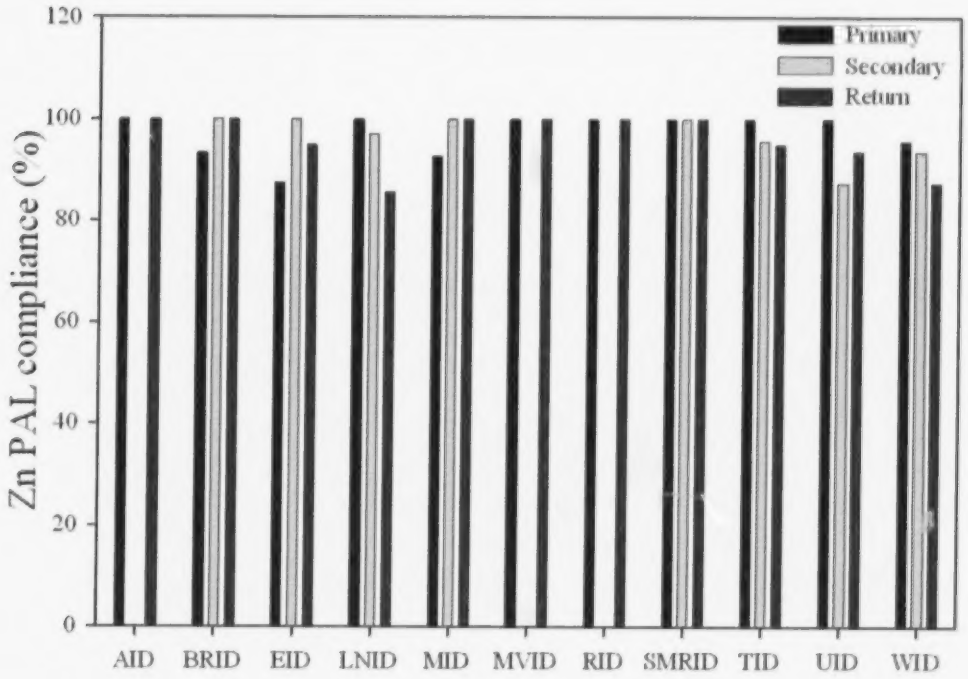

Fig. 76. Detection frequencies of zinc (Zn) by irrigation district and site type.

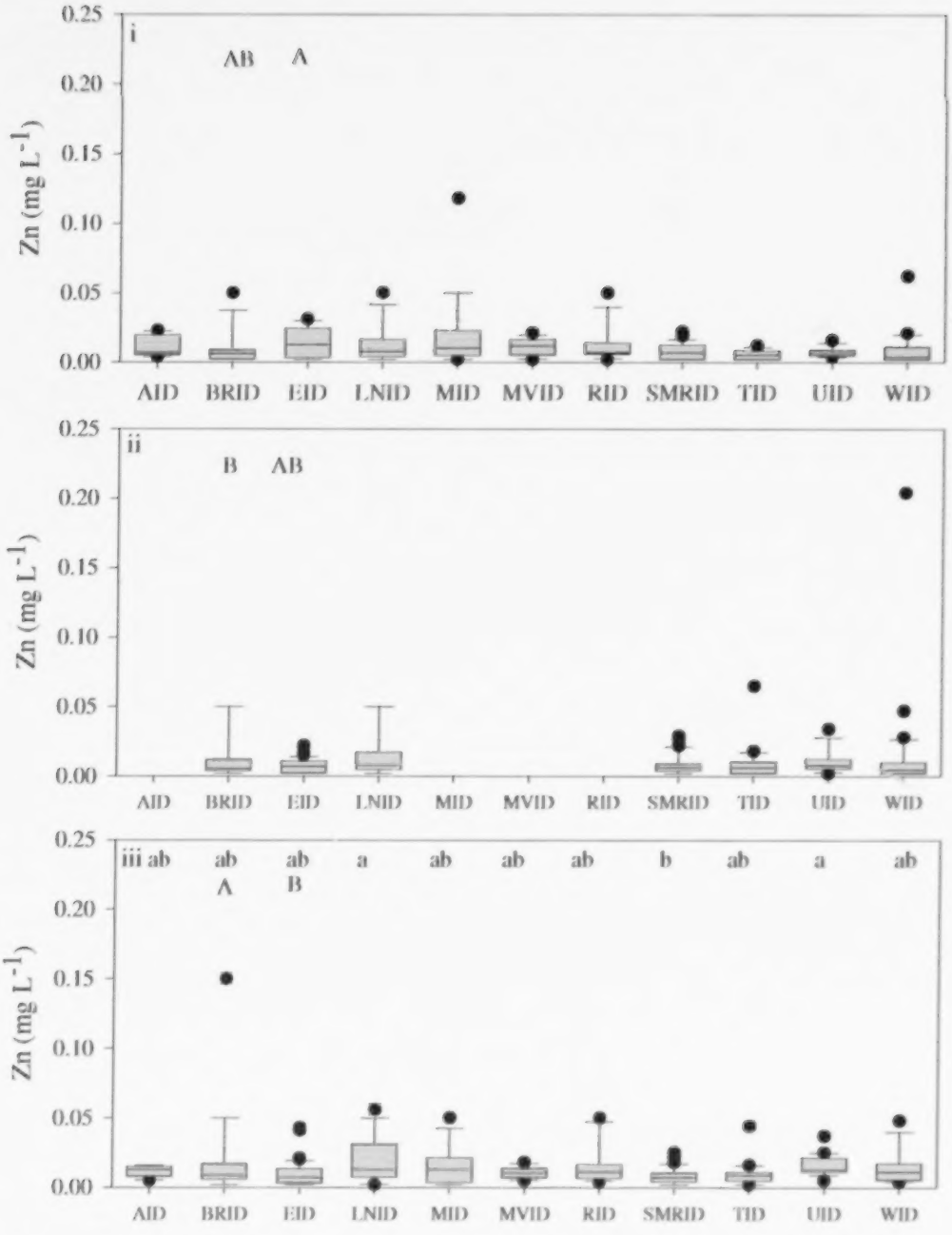

Fig. 77. Boxplots of zinc (Zn) concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

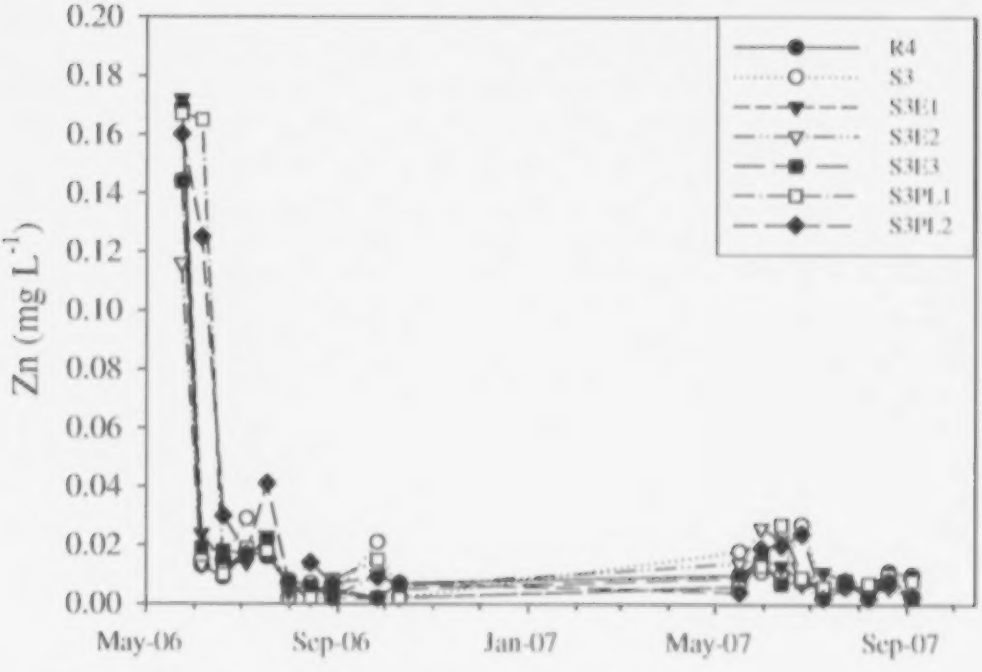

Fig. 78. Zinc (Zn) concentrations at the seven representative sites.

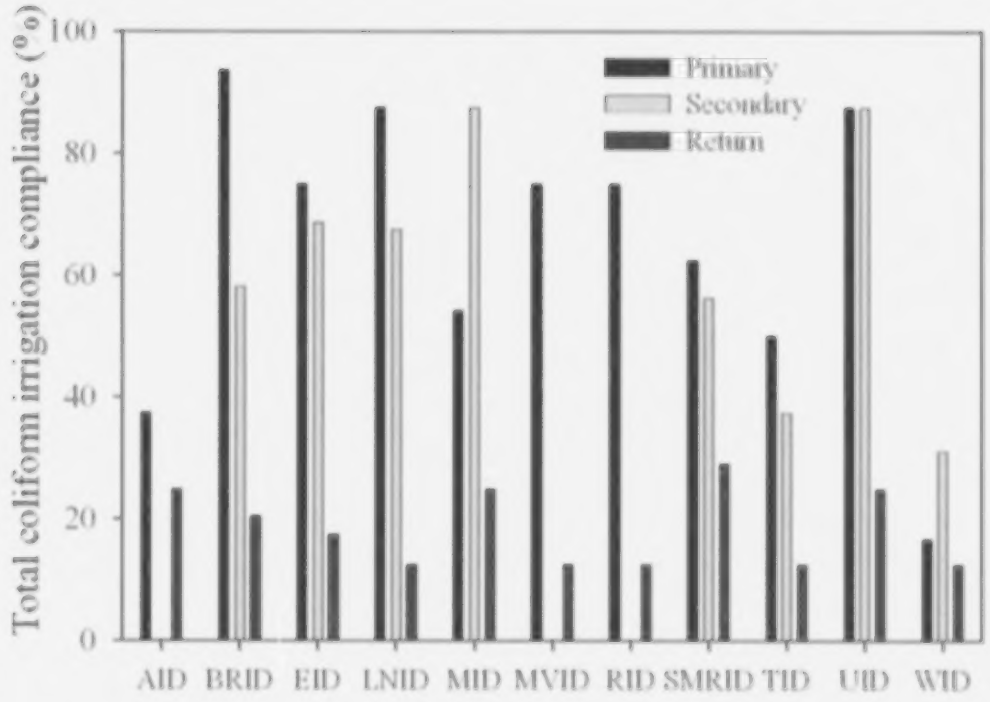

Fig. 79. Percent compliance with CCME total coliform guidelines for irrigation (1000 per 100 mL, CCREM 1987) by irrigation district and site type.

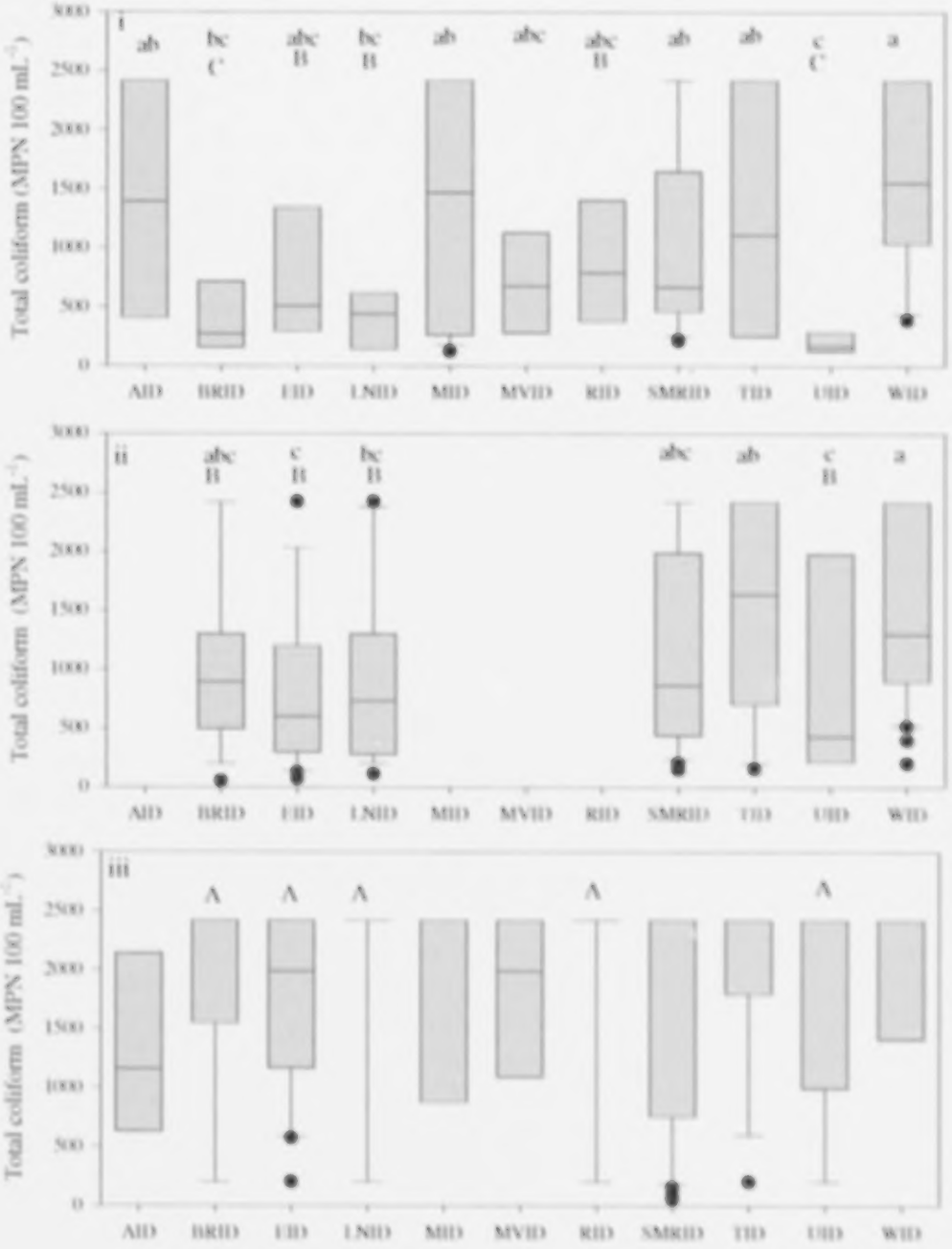

Fig. 80. Boxplots of total coliform concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

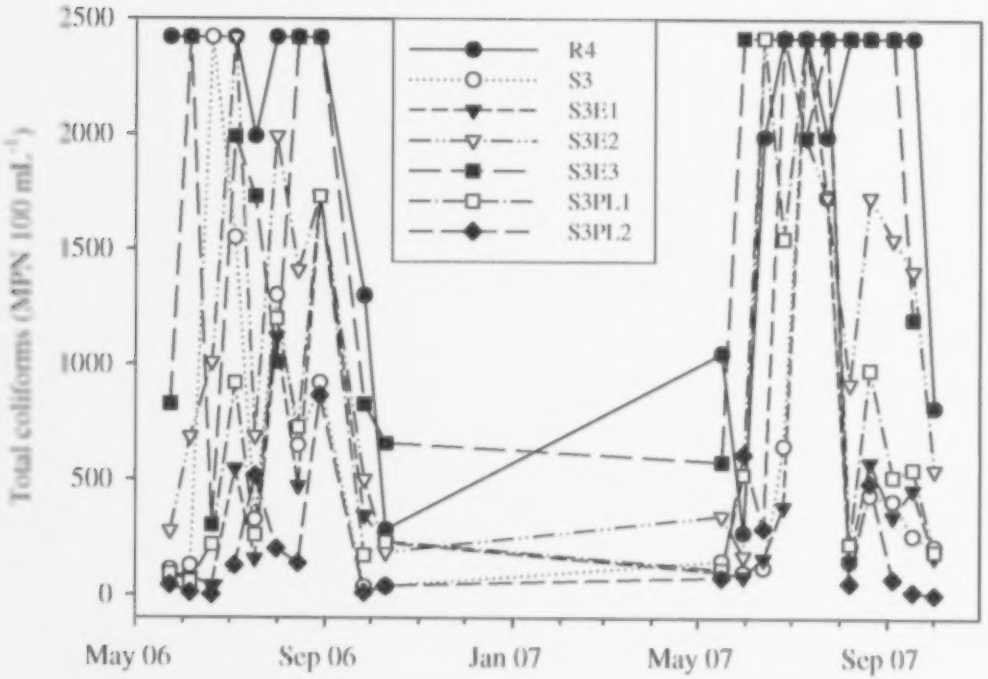

Fig. 81. Total coliform concentrations at the seven representative sites.

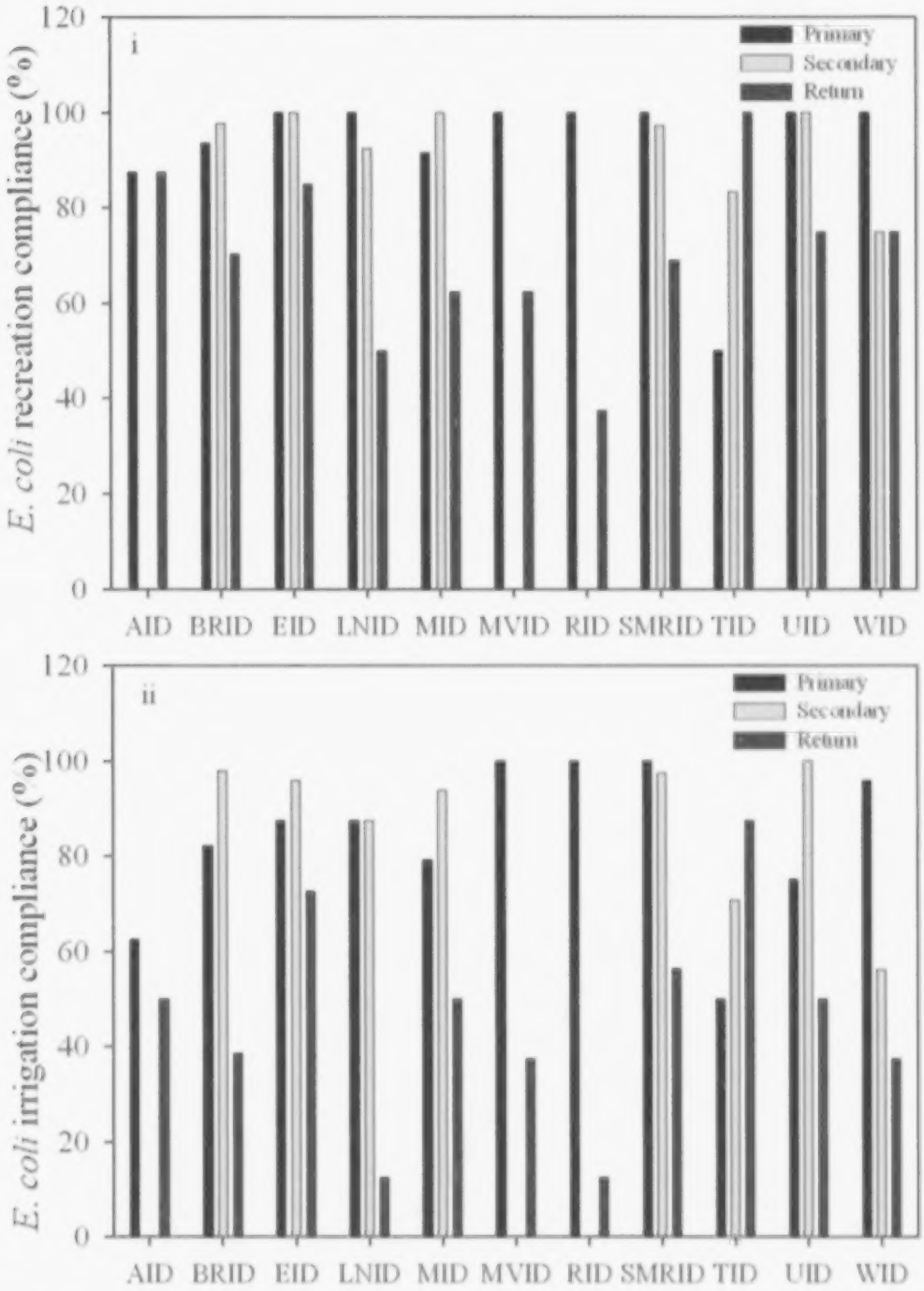

Fig. 82. Compliance with *Escherichia coli* (*E. coli*) (i) recreation (Alberta Environment 1999) and (ii) fecal coliform irrigation guidelines (CCREM 1987) by irrigation district and site type.

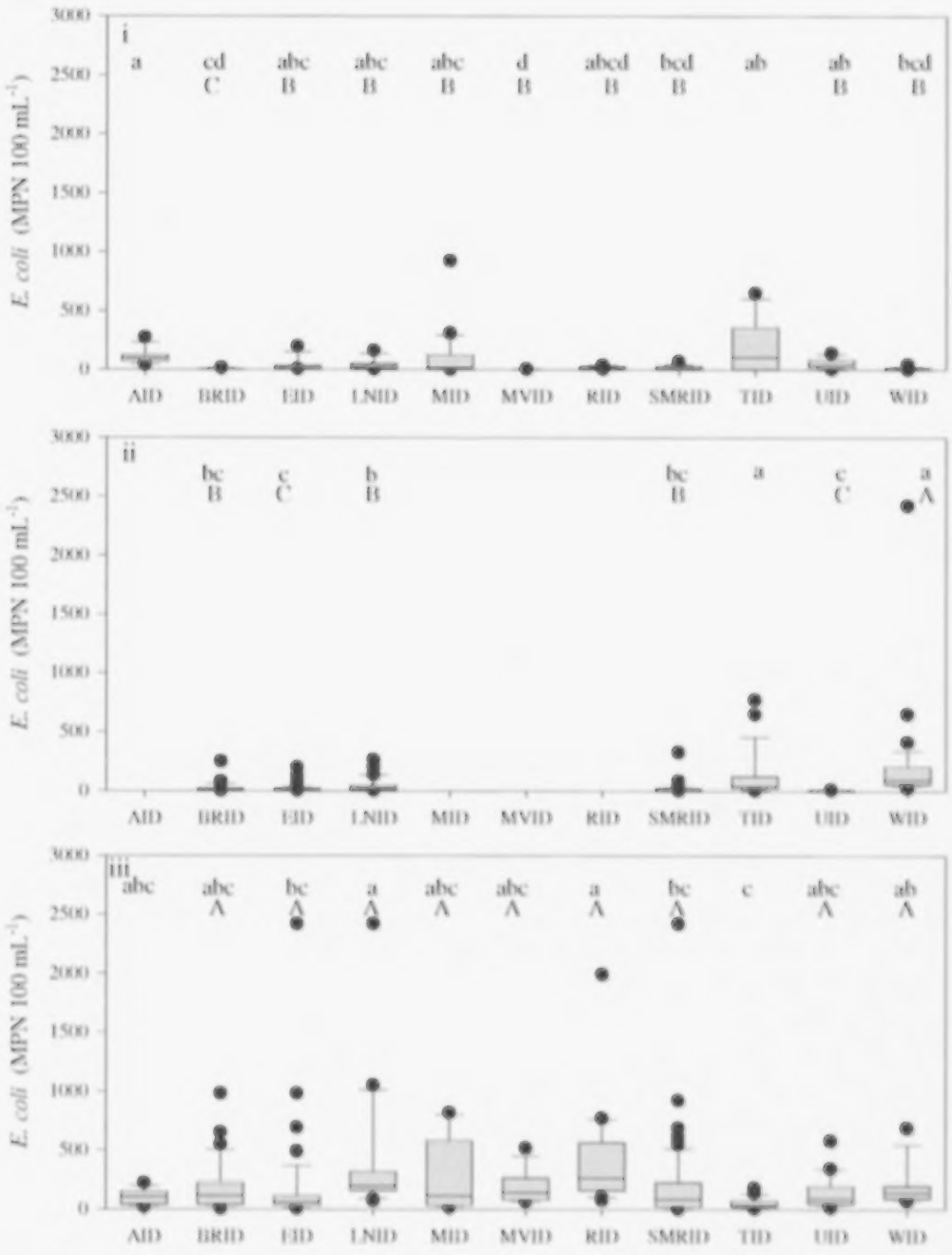
i
ii
iii
E. coli (MPN 100 mL-1)
3000
2500
2000
1500
1000
500
0
a cd abc abc abc d abcd bcd ab ab bcd
C B B B B B B B
bc c b bc a c a
B C B B C A
abc abc bc a abc abc a bc c abc ab
A A A A A A A A A A
AID BRID EID LNID MID MVID RID SMRID TID UID WID

Fig. 83. Boxplots of *Escherichia.coli* (*E. coli*) concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

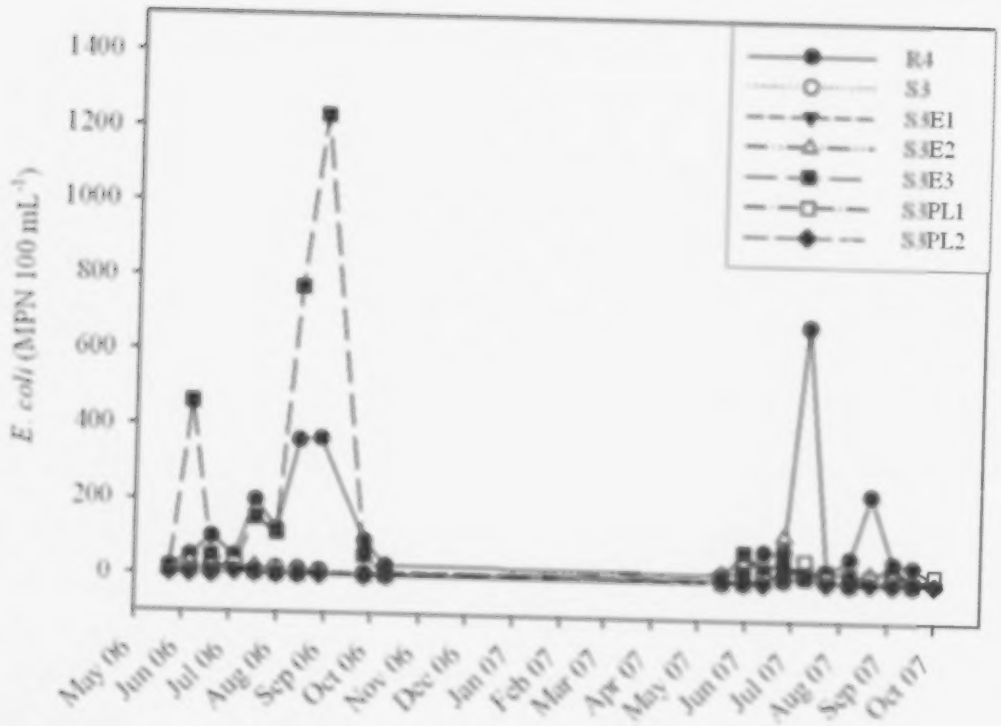

Fig. 84. Concentrations of *Escherichia coli* (*E. coli*) at the seven representative sites.

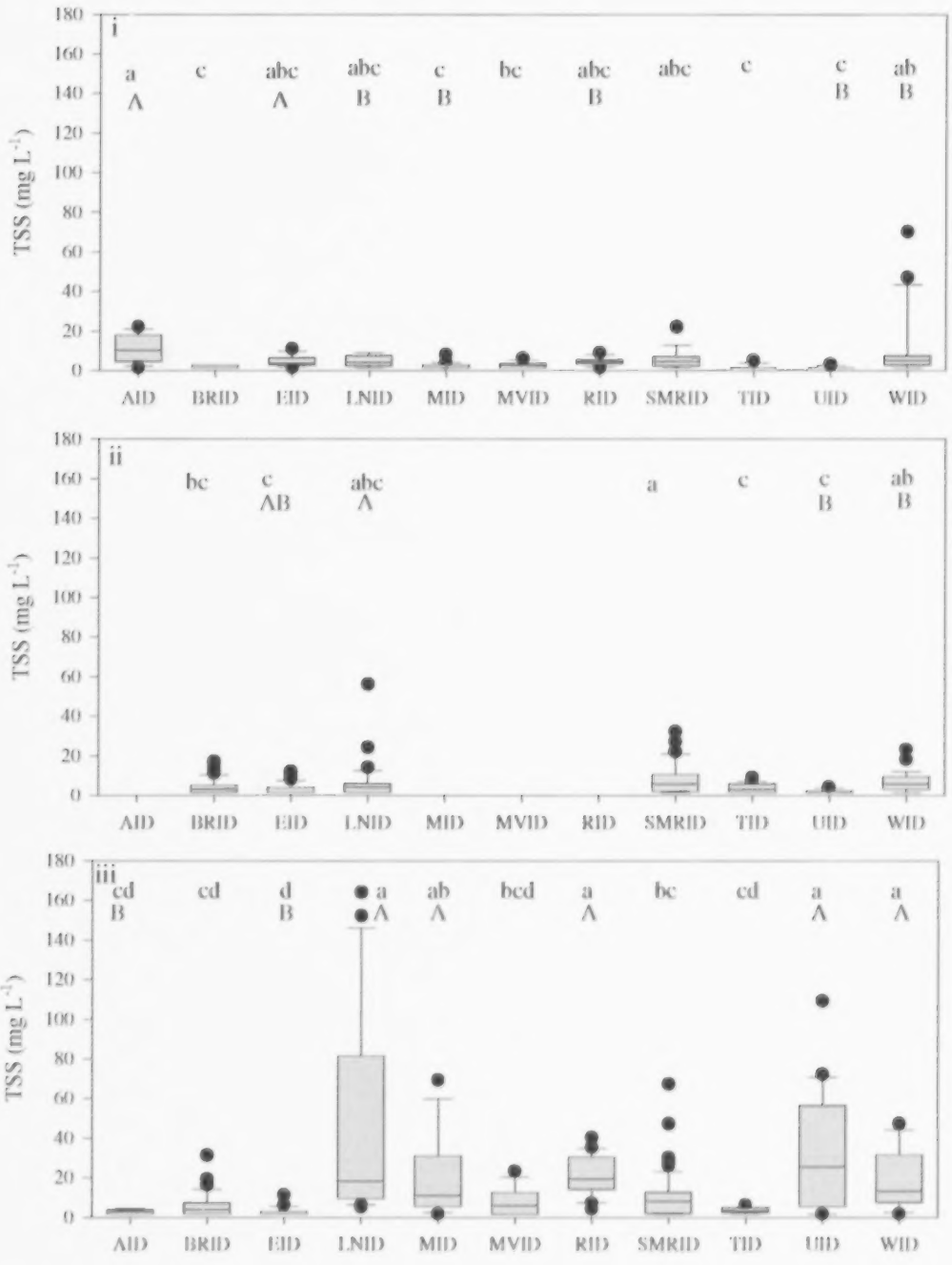

Fig. 85. Boxplots of total suspended solids (TSS) concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

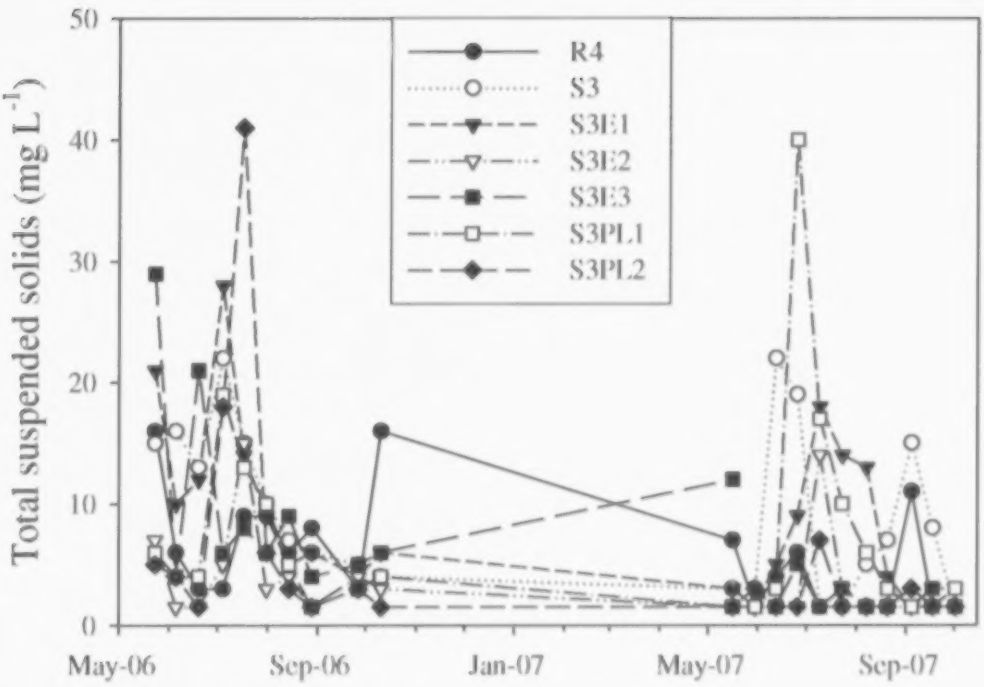

Fig. 86. Total suspended solids in the seven representative sites.

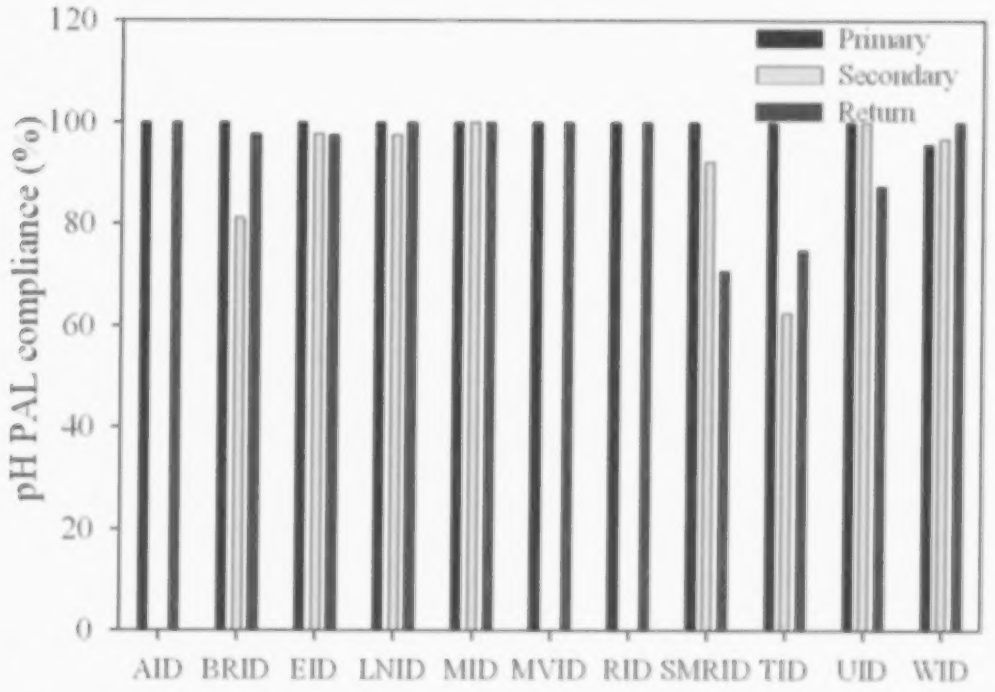

Fig. 87. Percent compliance with CCME pH guidelines for the protection of aquatic life (PAL) (6.5 to 9.0, CCREM 1987).

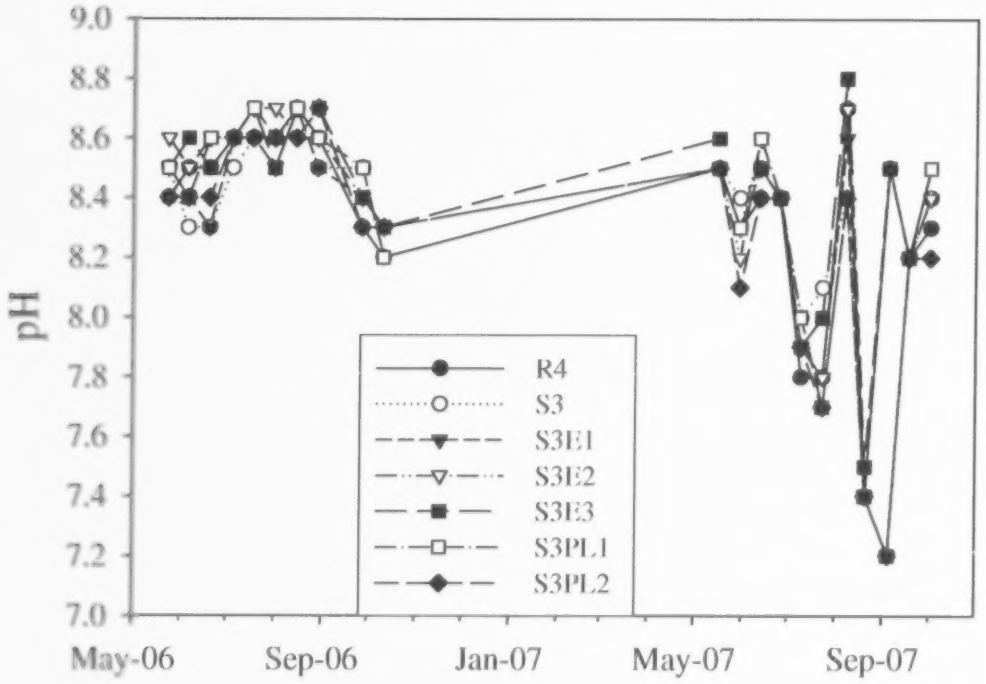

Fig. 88. pH at the seven representative sites.

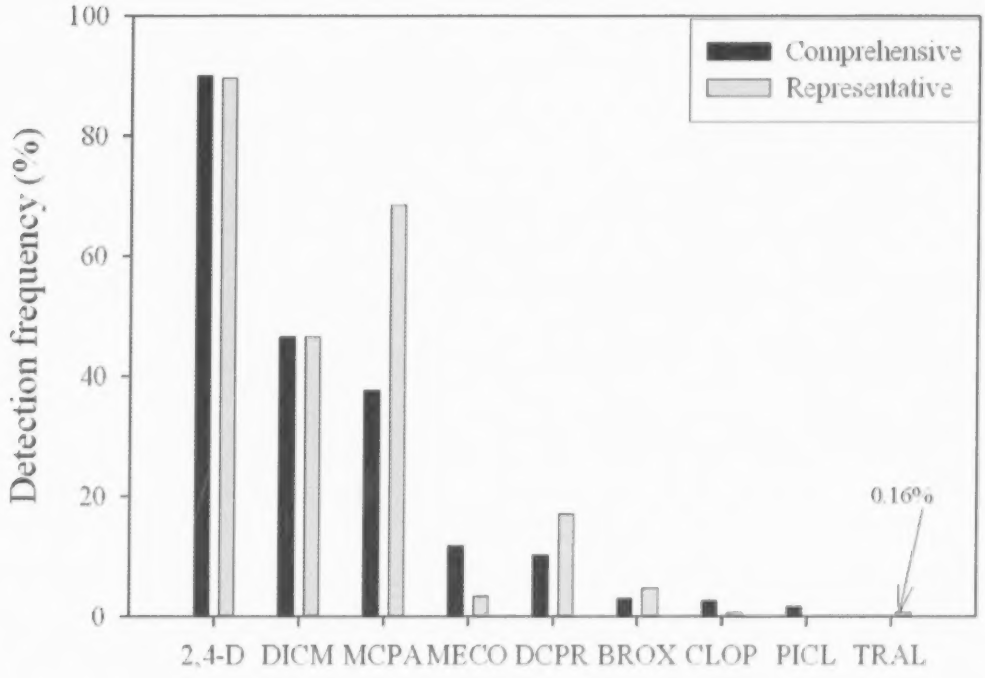

Fig. 89. Pesticide detection frequency of the nine detected pesticides in the 80 comprehensive and seven representative sites. Refer to Table 5 for full pesticide names.

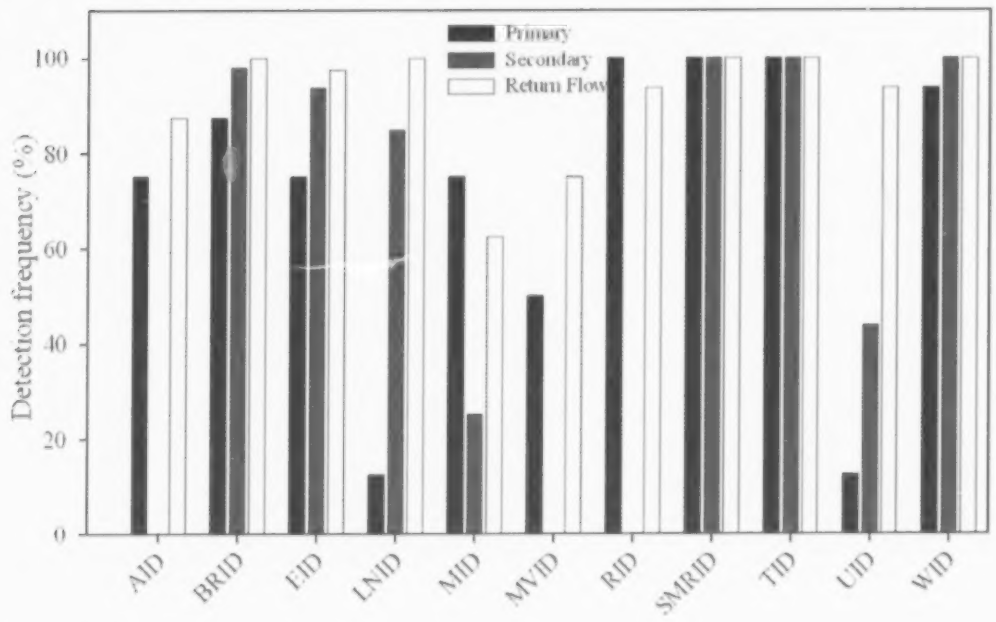

Fig. 90. Pesticide detection frequency by irrigation district and site type.

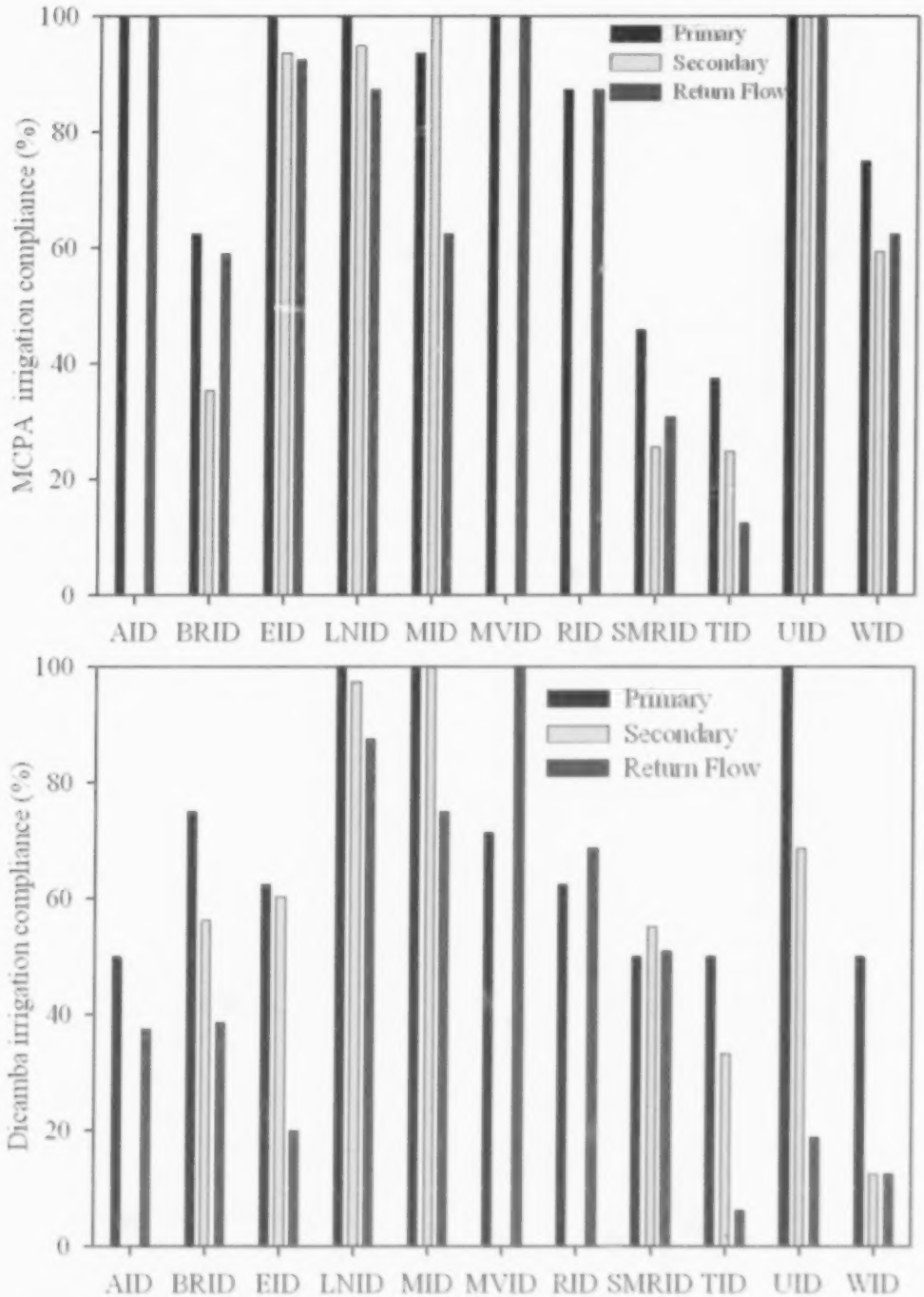

Fig. 91. Percent compliance of (i) MCPA and (ii) dicamba with CCME irrigation guidelines (CCME 1999) for all samples by irrigation district and site type.

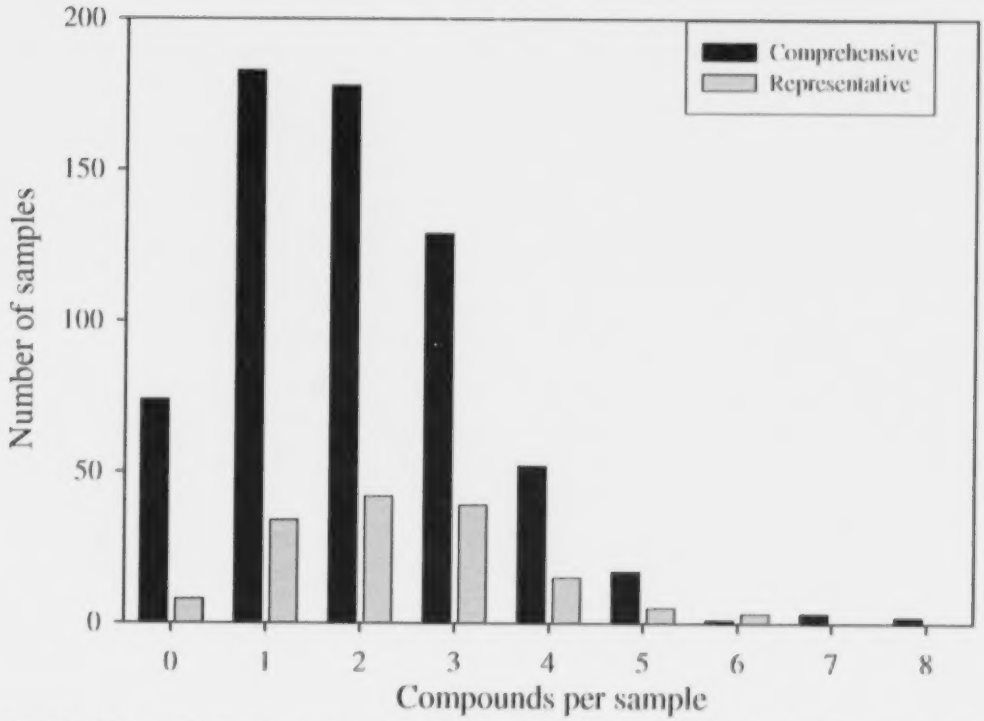

Fig. 92. The number of compounds per sample in the comprehensive and representative sites.

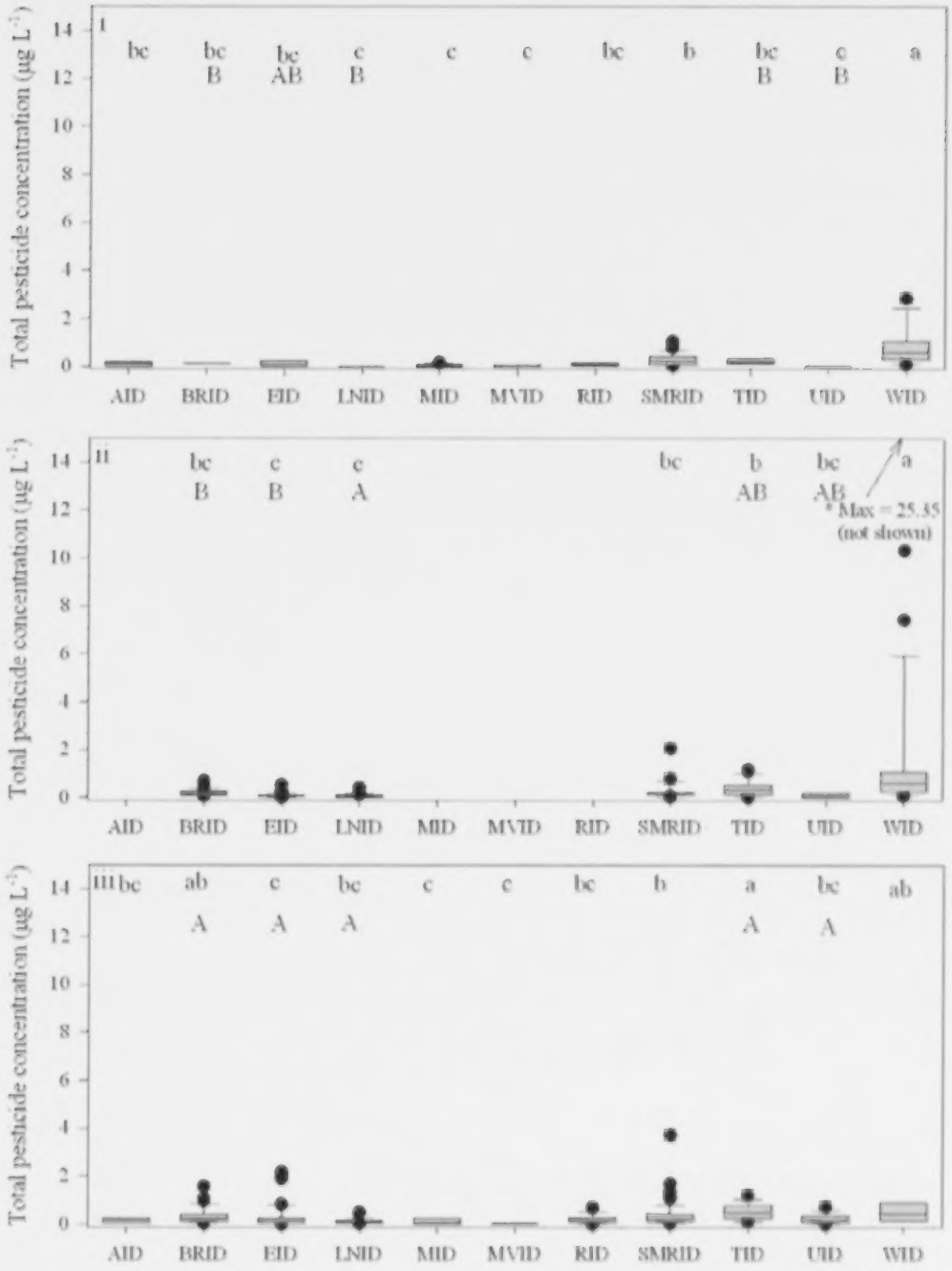

Fig. 93. Boxplots of total pesticide concentrations in (i) primary, (ii) secondary and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

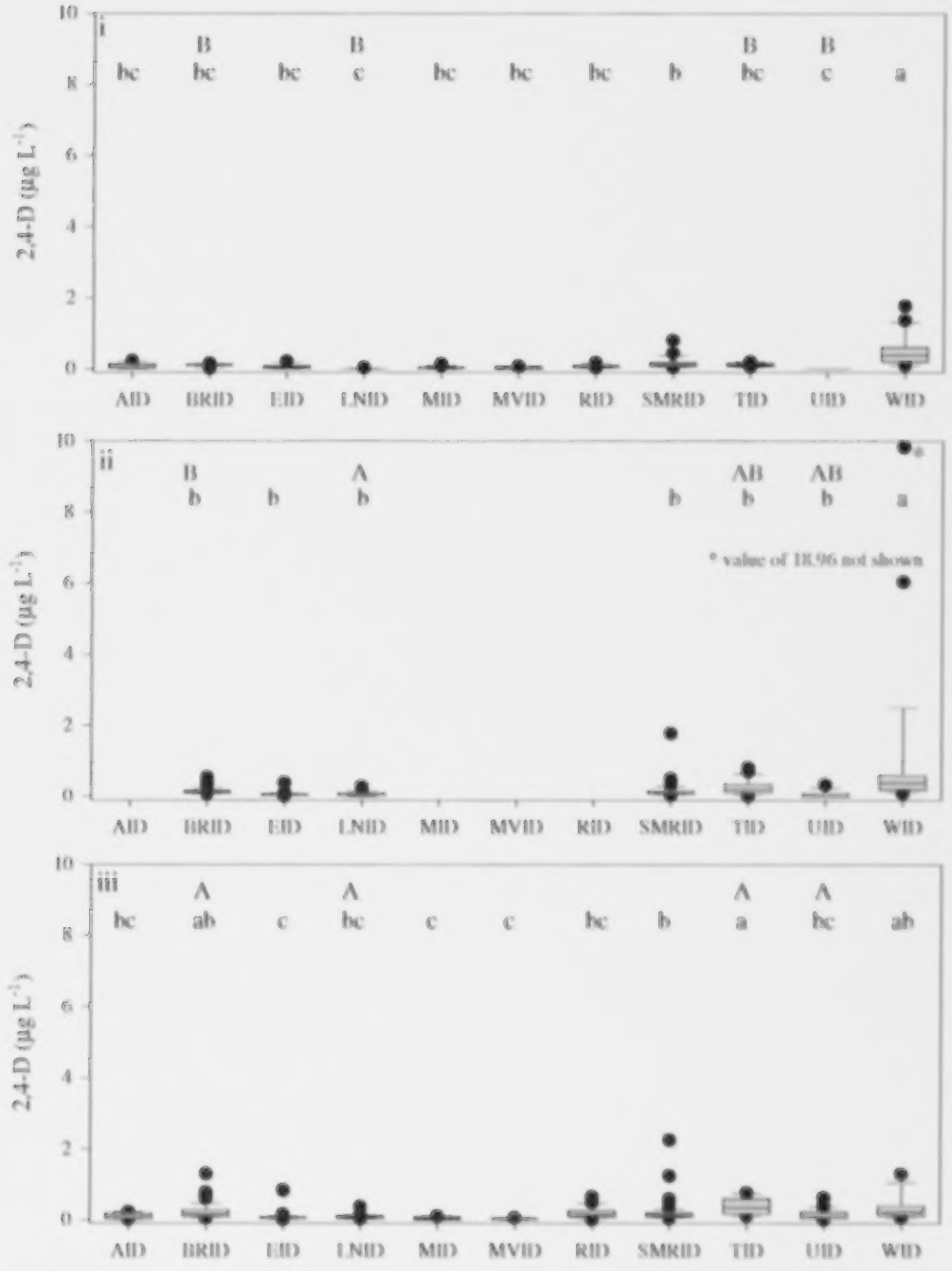

Fig. 94. Boxplots of 2,4-D concentrations in (i) primary, (ii) secondary, and (iii) return flow sites by irrigation district. Boxes with different lowercase letters are significantly different from the same site type in other irrigation districts (horizontal comparisons), while boxes with different uppercase letters are significantly different within each irrigation district (vertical comparisons) at $p<0.05$.

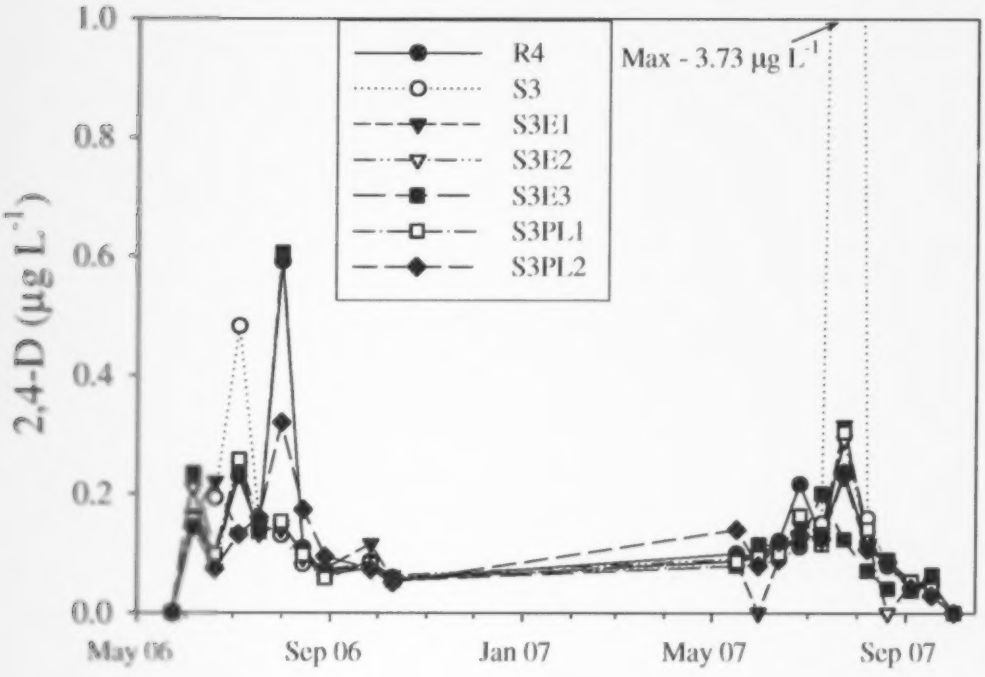

Fig. 95. 2,4-D concentrations at the seven representative sites.

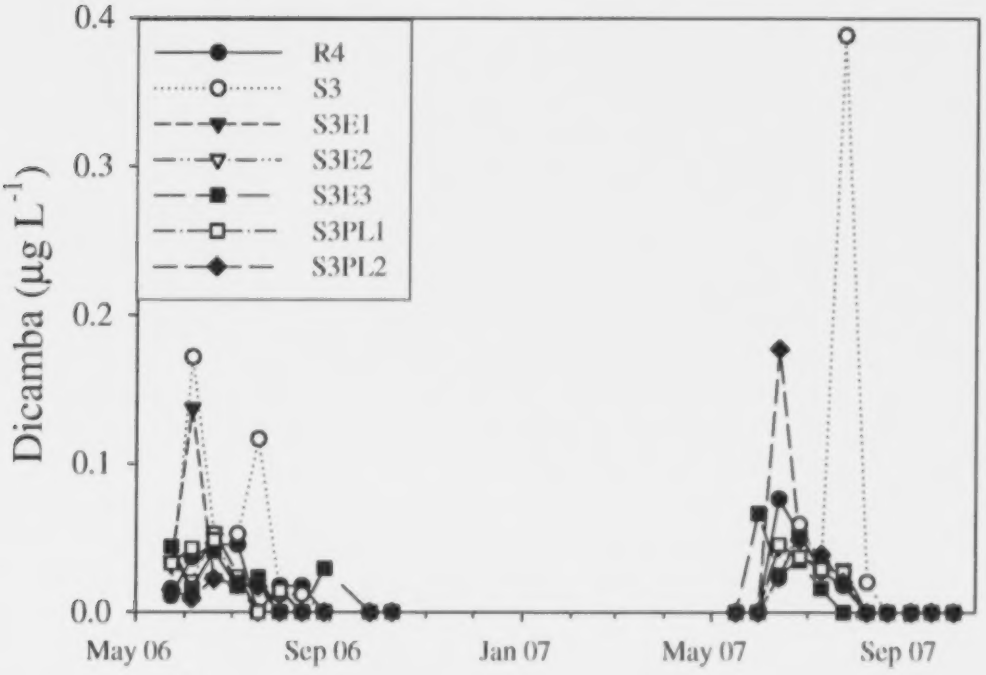

Fig. 96. Dicamba concentrations at the seven representative sites.

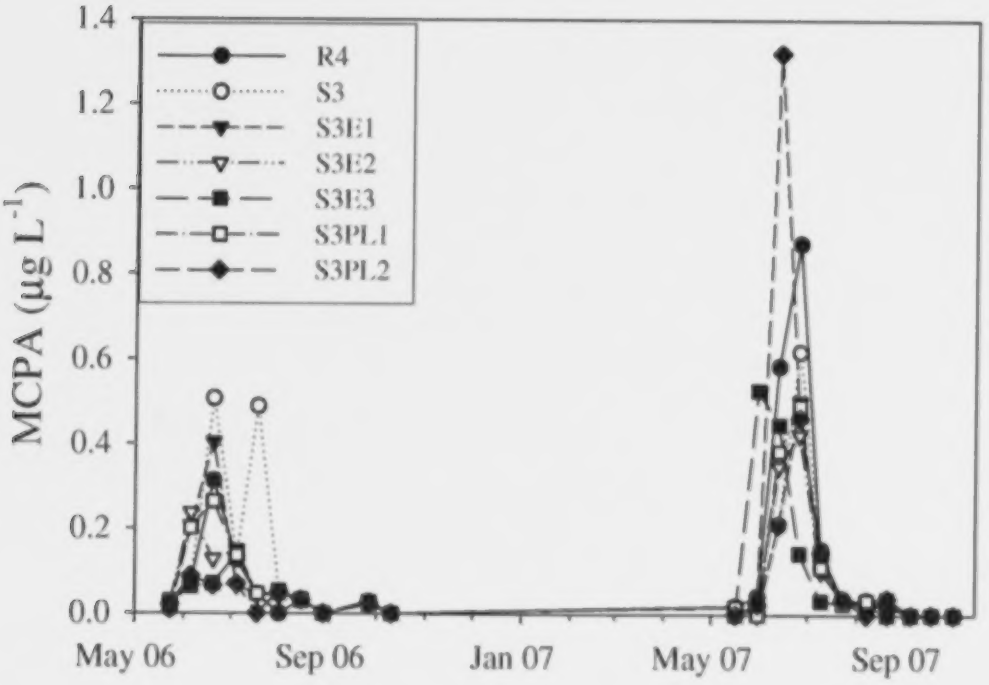

Fig. 97. MCPA concentrations at the seven representative sites.

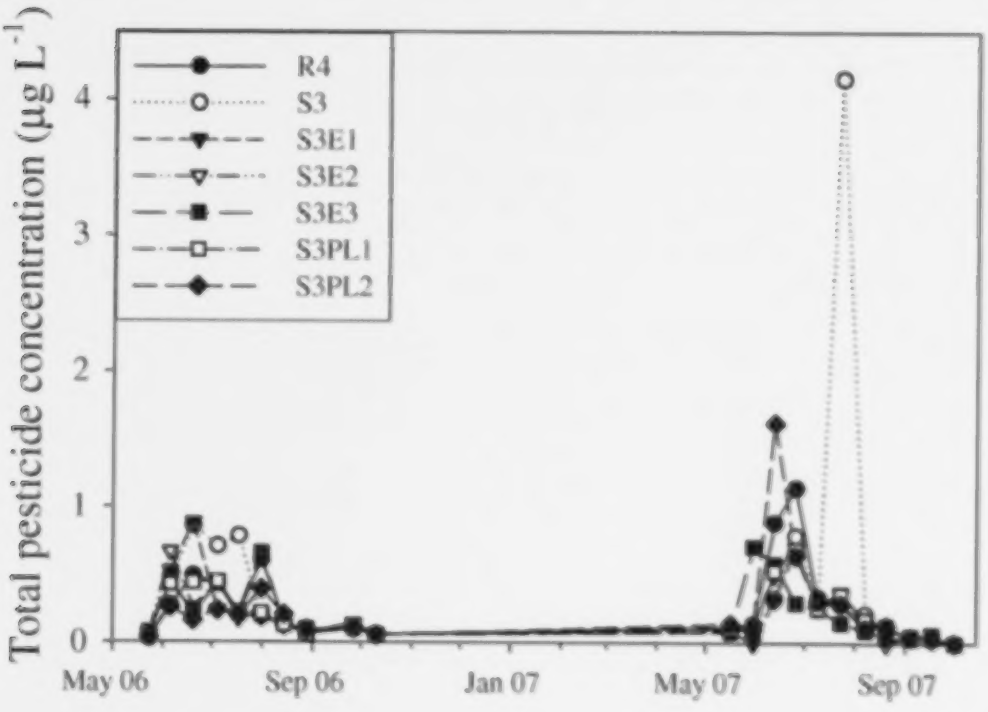

Fig. 98. Total pesticide concentrations at the seven representative sites.

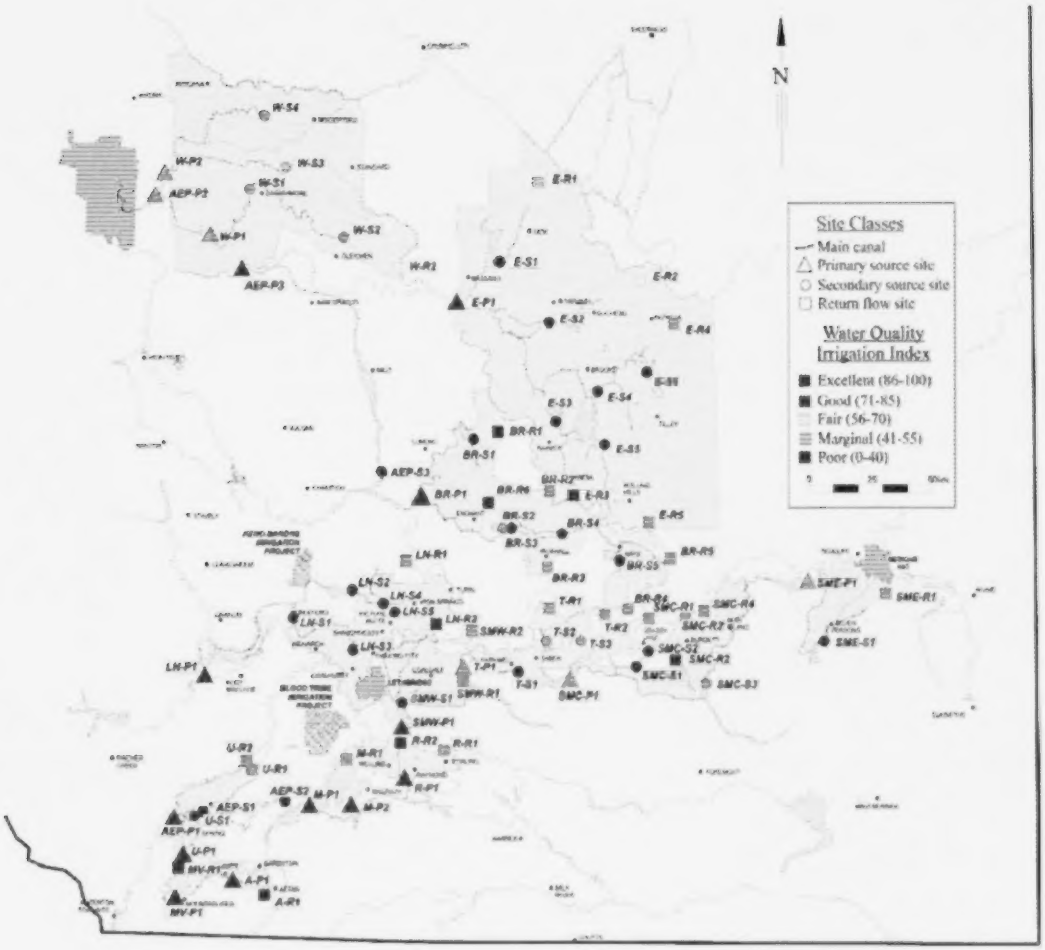

Fig. 99. Irrigation water quality index scores at the comprehensive study sites.

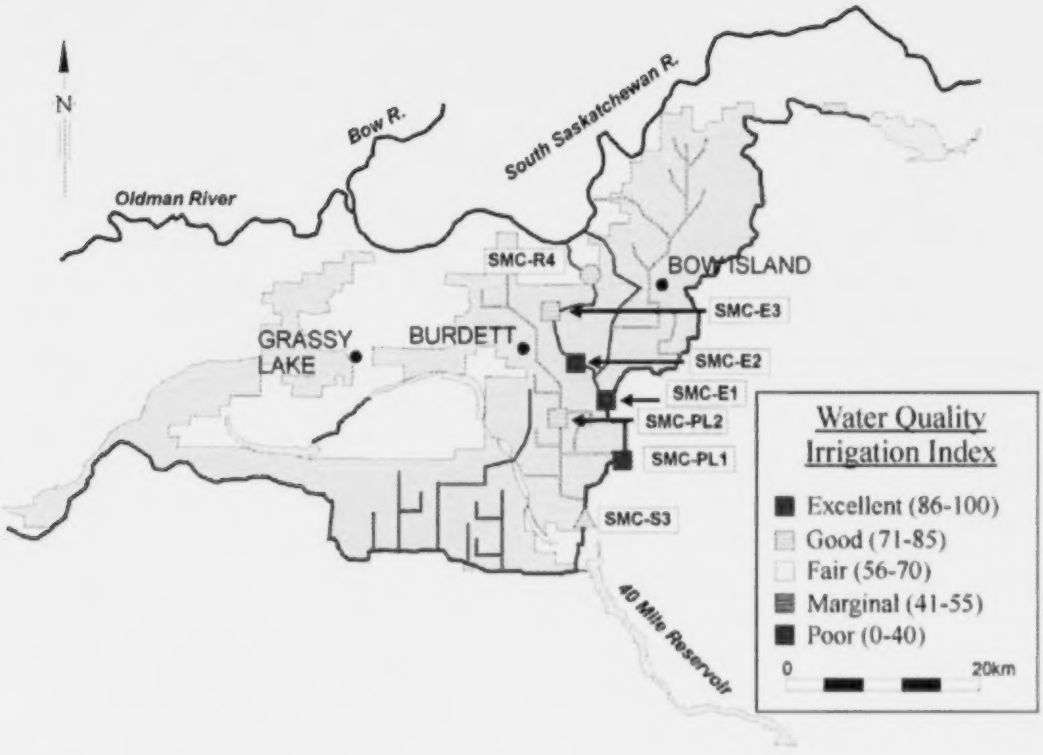

Fig. 100. Irrigation water quality index scores at the representative sites.

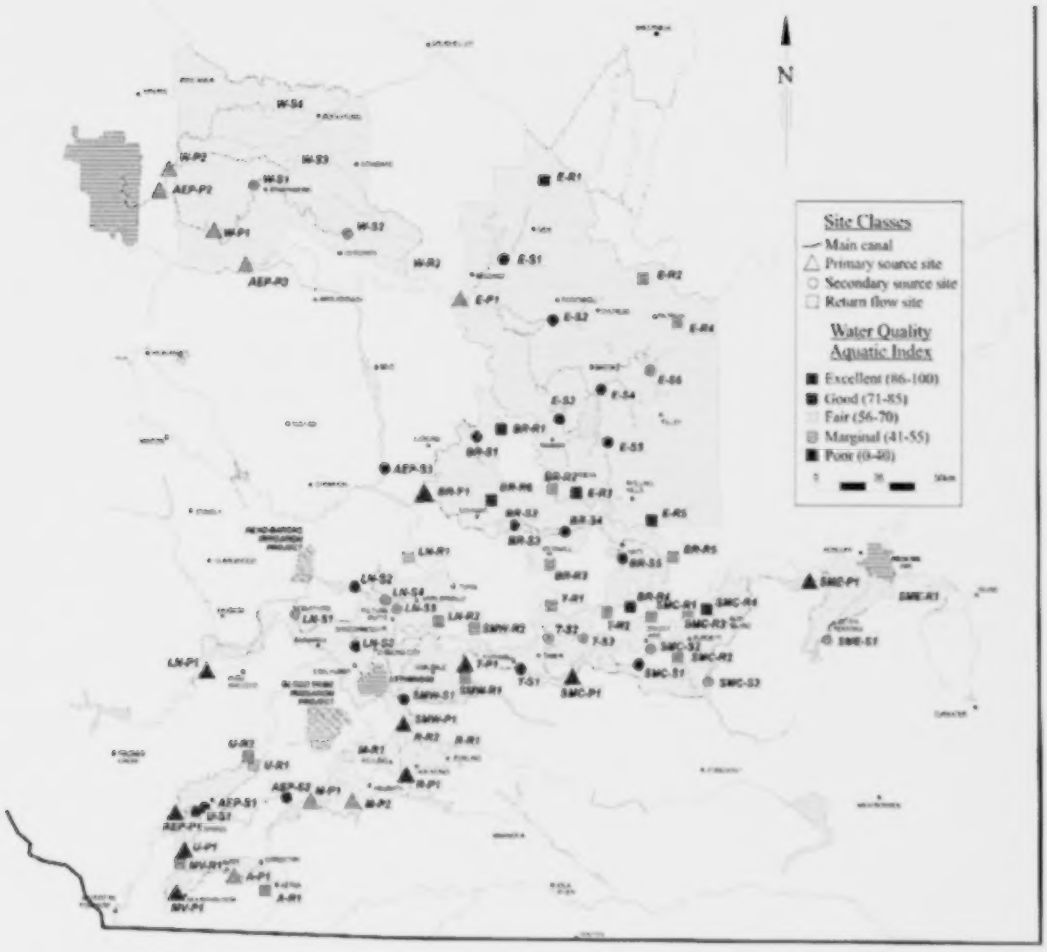

Fig. 101. Protection of aquatic life water quality index scores at the comprehensive sites.

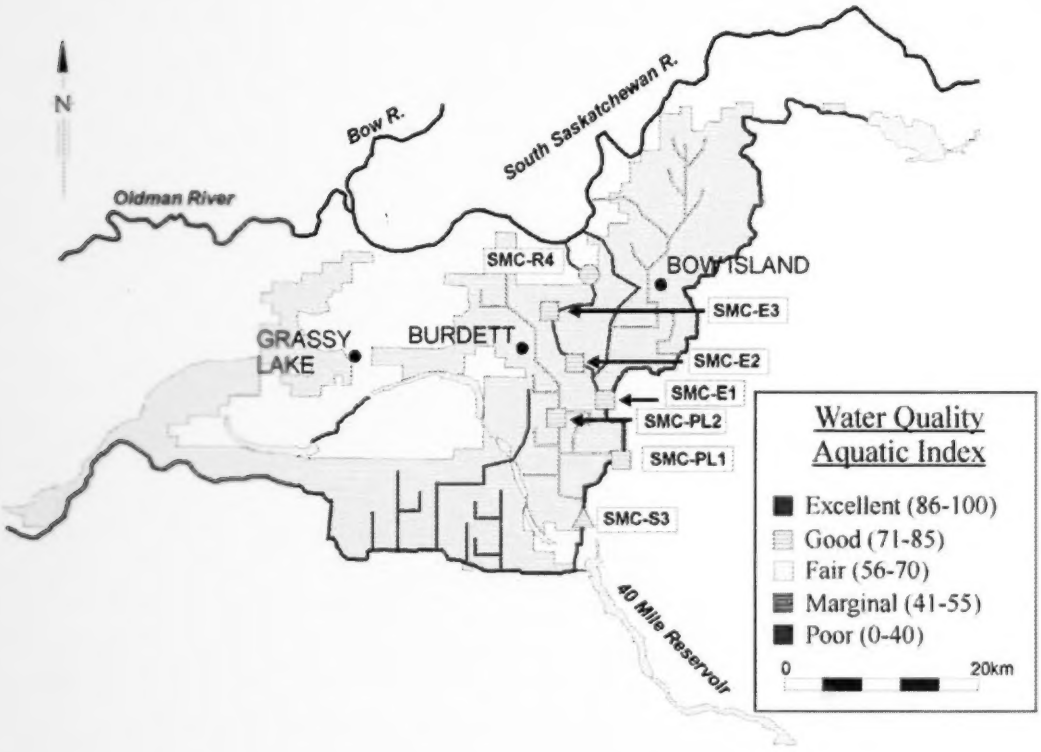

Fig. 102. Protection of aquatic life water quality index scores at the representative sites.